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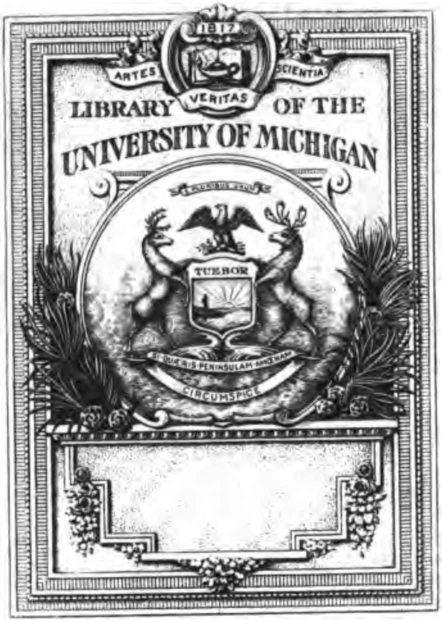
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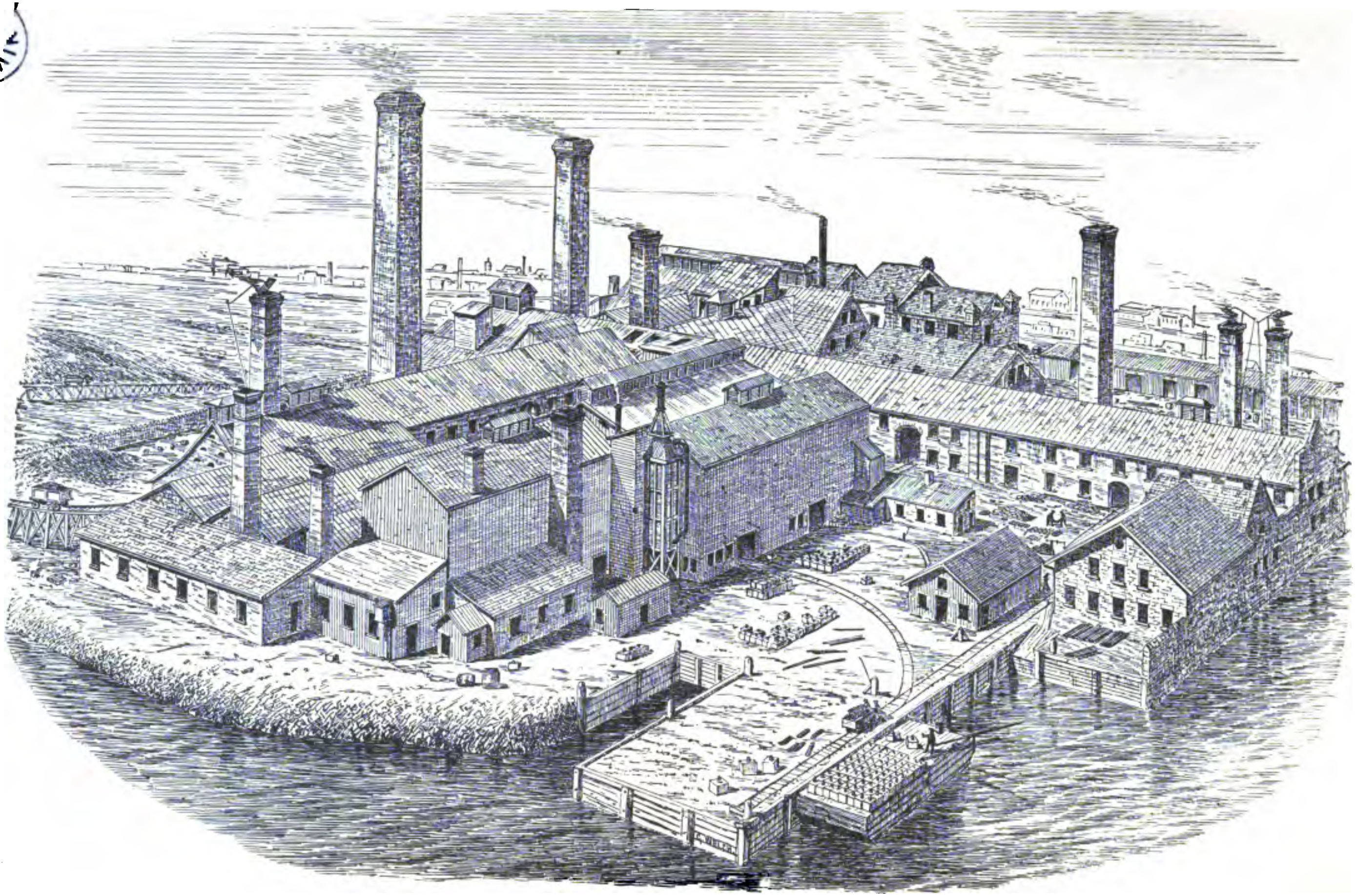

The Engineering & Mining Journal.

BIRD'S-EYE VIEW OF THE BALTIMORE COPPER-WORKS.

Operated by Messrs. Pope, Cole & Co., Baltimore, Md.

Swansea, Henry Hussey Vivian 32552.

COPPER SMELTING:

Its History and Processes.

BY

HENRY HUSSEY VIVIAN, M.P.

A Lecture delivered at Swansea, in the Theater of the Royal Institution of South Wales, December 20, 1880.

A HISTORY OF THE BALTIMORE COPPER WORKS AT CANTON, MARYLAND; SKETCHES OF THE FOREST COPPER WORKS AND THE HAFOD COPPER WORKS, SWANSEA, SOUTH WALES.

WITH ILLUSTRATIONS

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INTRODUCTION.

The lecture on Copper Smelting which we here present to the public was delivered on the 20th of December, 1880, at the Royal Institution of South Wales, Swansea, by the President of the Institution, Mr. Henry Hussey Vivian, M.P. for Glamorganshire. The original and exclusive source from which we were enabled to reproduce the lecture for the columns of the Engineering and Mining Journal was the *Cambrian*, of Swansea, in its issues of December 24th and 31st, 1880, copies of which, we are informed, were "all sold out the day of issue." It appeared in the Engineering and Mining Journal in the issues of March 26th, April 2d, April 9th, and April 16th, 1881. Curiously enough, therefore, those numbers of the Engineering and Mining Journal and the pages of this reprint offer not merely to Americans but also to English metallurgical students the only means of obtaining what one of the practical copper smelters of this country characterizes as "the most valuable article on copper smelting" he has "ever read." Mr. Richard Taylor, the senior member of the eminent mining firm of John Taylor & Sons, of London, writes as follows: "We have to thank you for the copies of your Journal containing the extremely interesting lecture on Copper Smelting by Mr. Hussey Vivian. It is singular that we should first have the opportunity of reading this in an American journal, and it affords good proof of the advantages you possess in obtaining interesting matter from the old country."

We may state that copper smelting has been carried on in the Swansea District since the time of Queen Elizabeth, and for some generations the Messrs. Vivian, of the Hafod Copper Works, Landore, Swansea, have been among the largest, if not the oldest, copper smelters in the district. Mr. John Henry Vivian, M.P., the present Mr. Vivian's father, was actively engaged in copper smelting during the whole of his business lifetime, and the present Mr. H. H. Vivian has also been actively so employed for the past thirty-seven years. From such an authority, therefore, the information given will not only be of general use, but will be of special value to all those interested in the metallurgy of copper as perfected to-day in the South Welsh District. Mr. Vivian says: "The 'South Wales process' of copper smelting is now the dominant one of the whole world." The lecture first treats exhaustively of the history of copper and copper smelting from the earliest times, and then proceeds to define the "system" of copper smelting as practiced at Swansea, through its various "processes," until the final one of "refining" is reached, when Mr. Vivian graciously gives way, and reads what he characterizes as "an admirable description of our refining process, written by Mr. William Morgan, who has been a practical refiner all his life."

While this lecture was publishing in the columns of the Engineering

AND MINING JOURNAL, we received numerous and urgent requests from experts and others to put the valuable history and discussion into permanent and attractive form; and in response to these requests, this pamphlet makes its appearance. Following Mr. HUSSEY VIVIAN'S lecture, a history of the Baltimore Copper Works, specially prepared for this work, has been presented as of special interest. To this are added accounts of the Forest Copper Works and of the Hafod Copper Works, at Swansea, the latter under the management of Mr. HUSSEY VIVIAN himself; and a short paper in which the year is fixed in which the copper trade began in Swansea. For these we are indebted to a very rare work, printed but not published, by Major GRANT FRANCIS, F.S.A., of Swansea. It is hoped that the three beautiful illustrations, prepared at great pains, will serve to enhance the value of this admirable metallurgical essay by one of the most successful and eminent copper smelters of the world.

EDITORIAL ROOMS,
ENGINEERING AND MINING JOURNAL, July, 1881.

COPPER SMELTING:

ITS HISTORY AND PROCESSES.

A LECTURE

BY HENRY HUSSEY VIVIAN, M.P.

Delivered at Swansea in the Theater of the Royal Institution of South Wales.

The President of the Royal Institution for the present year, H. H. Vivian, Esq., M.P., delivered the last of the pre-Christmas course of lectures in the theater of the Institution, at Swansea, South Wales, on Monday evening, December 20th, 1880, before a large and attentive audience. Mr. Vivian said:

I shall endeavor in the lecture I am about to give on Copper Smelting to avoid on the one hand mere scientific and, on the other, mere technical details. My aim will be to tell you, as simply and concisely as I can, the story of Copper Smelting as I understand it; to import into it some of the experiences of the thirty-seven years during which I have been actively engaged in it; and in doing so, I hope that I may succeed in giving a few grains of useful information, both positive and negative; that is, both what to do and what not to attempt. Smelting is a "dry" process necessarily, and although it has much "fire" in it, I fear I can impart none to my tale to-night. Now it must occur to any one, I think, in considering this question, to ask in the first instance how and when Copper Smelting began. I am not aware that a perfectly satisfactory reply can be given to that question. The only authentic history we possess of very early times is the Bible; in it we find constant mention of brass, while the word "copper" occurs only once in the Old Testament, namely, in the 8th Ezra, 27th verse, where it is stated that "two vessels of fine copper, precious as gold, were offered with gold and silver vessels to the house of God;" but even in that case the annotation in the margin is, instead of "fine copper," "yellow or shining brass." It seems, therefore, uncertain whether, even in this solitary instance, "fine copper" was used. There is, indeed, grave reason to doubt whether pure copper was used in very early ages, either in Europe or Asia. On the other hand, brass, or rather bronze, was in common use, although the above extract, dating only 457 years B.C., seems to assign to it a very high value. I say bronze and not brass, because the alloy was copper and tin, which is, properly, "bronze," while "brass" is an alloy of copper and zinc. What we now call brass was produced by heating metallic copper and a mineral called "Lapis Calaminaris" together with charcoal in a crucible, whereby the carbonic acid was driven off, and the zinc contained in the "Lapis Calaminaris" was reduced to metallic zinc, and thus alloyed with the copper. It seems also probable, from the evidence produced by Doctor Percy, in his valuable work on zinc, that the furnace deposits produced in smelting zinciferous copper ores were used to produce brass by heating them with metallic copper precisely as in the case of Lapis Calaminaris. The metal thus produced was called "Orichalcum" by the Romans, in contradistinction to "Æs," which, although often ignorantly translated brass, was really bronze, that is, copper and tin with occasionally some lead—9 to 1. "Orichalcum" seems to have been well known at the commencement of the Christian era; but I can find no evidence of its earlier use, and I think we may assume that when "brass" is spoken of in the Bible, an alloy of copper and tin, not copper and zinc, is meant. There is scarcely a book in the Old Testament in which the word brass does not occur; in fact, it is mentioned 38 times in the Pentateuch, excluding Deuteronomy. Beginning in Genesis, we find, in the 22d verse of the 4th chapter, that "Zillah bare Tubal Cain [the seventh in descent from Adam]; he was an instructor of every artificer in brass and iron." The date assigned to this chapter is 3875 years before Christ. In the book of Exodus, there are ten separate cases in which brass is mentioned. The first is in the 25th chapter and 3d verse, where God directs Moses to instruct the children of Israel to bring "offerings of gold, and silver," and brass for the purpose of constructing the "Sanctuary," the supports and vessels of which were to be of brass; the date assigned to this is 1491 B.C. It would occupy too much of my time to attempt to go through the numerous instances in which brass is mentioned in the Old Testament; but I will first ask one moment to draw attention to the extent to which brass entered into the construction of the Temple of Solomon, B.C. 1005. We are told that King Solomon sent to Tyre for a man called Hiram, a worker in brass, "who was filled with wisdom and understanding, cunning to work all works in brass;" he cast two pillars, each 18 cubits high, or 32·832 feet high, nearly 33 feet—and 12 cubits or 21 feet in circumference, say 7 feet in diameter. He then cast a chapiter or capitol for each, 5 cubits or 9 feet high. Then follows a detailed description of the brass work with which he ornamented these pillars, which stood on each side of the porch. He also made a molten sea of brass 18 feet in diameter, and twelve oxen of brass to support it. He made various other large bronze castings, richly ornamented and engraved with lions, oxen, and cherubim. Twenty-five verses are devoted to the description of Hiram's works in brass. We may deduce from this passage that the casting of bronze had attained great perfection nearly 3000 years ago; in fact, it would be a considerable work, even at the present moment, to cast bronze pillars 33 feet high and 21 feet in circumference, or a bronze basin 18 feet in diameter. To make such a casting, a large quantity of metal would have to be melted at once, not probably in crucibles, but in a cupola or reverberatory furnace, and great skill would be required in manipulating so heavy a casting. It is also clear that the art of molding was well understood. From whence did the copper and tin come, and who smelted it?

If we turn from the inspired history of the Bible to those records of past ages which are stored up in the barrows, lakes, refuse heaps, and battlefields of Europe, we find equally clear and indisputable evidence of the great antiquity of copper, not, indeed, as copper in its pure state, but as bronze. There seems no reason to doubt that bronze was the first metal used by man for the construction of implements and weapons. As a metallurgist, I should have certainly said, *à priori*, that iron, from the abundance of its ores, occurring, as I think I am safe in asserting that they do, in every known geological formation, and from the ease with which rich ores of iron can be reduced to metallic iron, ought to have been the first to attract the attention of man; but I am bound to say, that the evidence adduced by my friend, Sir John Lubbock, in his admirable work on Pre-Historic Times, and by others, appears to me to leave no doubt that an age of Bronze succeeded the Stone age, and preceded the Iron age. I think I am right in saying that no attempt has been made to fix any thing like an approximate date to the commencement of the Bronze age; but Sir John Lubbock appears to be of opinion that the transition from bronze to iron took place about 900 years B.C. This would be nearly 2800 years ago, and through what a long vista must we look back before we see the commencement of the age of bronze in Europe!

But did it commence in Europe? The best authorities say "No," and I think they establish their case. It is almost certain that the use of bronze was introduced from the East, either as a branch of commerce, or, as seems more probable, by the incursion of a powerful and warlike race, large in stature and better armed than the men of the Stone age, who were consequently speedily extirpated by them. This inference is drawn from the bones found in Bronze age tumuli. Professor Rolleston tells us that "Hesiod (who is supposed to have written about 900 years B.C.), in his *Works and Days*, had somehow become as much impressed with the vast size and brute strength of the bronze-using people as I have become from actual handling of the bones." He also says, "All this seems to me to point to a conquest of this country having been effected by bronze-using invaders, who came in great numbers, probably, as has been elsewhere suggested, from the Cimbric peninsula." The relics of this race prove that they were a people of higher civilization than the men of the Stone age. During this age, true bronze alone is found; that is to say, an alloy of copper and tin; during the Roman period, lead was frequently introduced into the alloy, but during the same period bronze was not used for the manufacture of weapons or cutting implements; iron and steel had taken the place of bronze in the manufacture of swords spearheads, and the like.

It now becomes an interesting question to consider, whether, during the Bronze age, the materials of which it was made were produced in Europe or imported into it? Sir John Lubbock says: "The impurities in the bronze indicate that the copper ore was not all derived from one locality, and lastly, the discovery of molds in Ireland, Scotland, England, Switzerland, Denmark, and elsewhere, proves that the art of casting in bronze was known and practiced in many countries. Under these circumstances, it appears most probable that the knowledge of metal is one of those great discoveries which Europe owes to the East, and that the use of copper was not introduced into our continent until it had been observed that, by the addition of a small quantity of tin, it was rendered harder and more valuable." It seems almost certain that Europe, at least, never passed through a copper age. Implements of pure copper are extremely rare; a few have been found in Ireland. Some of these are of doubtful composition, and one is supposed to have come from America, where, undoubtedly, an age of copper did exist. That, however, is explained by the massive deposits of pure copper which occur on the shores of Lake Superior, which bear evidence of extensive and very early working. The remarkable similarity of bronze implements, wherever found, is an additional proof of their early importation, and that they came from a common center of manufacture, although the existence of molds in various countries, as before mentioned, shows that the implements were also cast in those countries, probably to meet the special tastes of the persons who were rich enough to buy them; the manufacture was probably carried on by re-casting bronze ingots brought from their distant source of production. This seems strange and contradictory in view of the existence of copper and tin in such abundance in Cornwall; but we have the distinct evidence of Cæsar that even in his day these islands imported their bronze, in the often quoted words, "*Ære utuntur importato.*" Further, I am not aware that there is any record or remains of very early copper smelting in Cornwall, or elsewhere in England. I do not speak of Roman days; for I believe there is some slight evidence of copper smelting in the North of England in Roman times; but I speak of the times of the true Bronze age—the men of the "Round," "Bell," "Bowl," and "Cone" shaped barrows in which bronze, and not iron, is found.

It is indeed a most interesting question, Whence came the bronze? Whether in the shape of celt, sword, spear, brooch, or ingot, which supplied those men with their weapons and ornaments? So far as I am able to form an opinion from the works I have read, I believe that it came from the East, and I agree with Professor Rolleston in the opinion he expresses in that most able paper which he read before the Bristol and Gloucestershire Archæological Society, "On the Three Periods known as the Iron, the Bronze, and the Stone Ages," from which I am largely quoting, and to which I owe many thanks. Professor Rolleston says: "Where was likely to be made the discovery of the advantages to be gained from alloying copper with tin, and so obtaining bronze? It was, of course, likely to be made in some district in which the ores of these two metals were to be found in proximity." When I say I agree in that, I must guard myself against being supposed in any way to assent to the theory enunciated by M. Wibel, that bronze was obtained by the direct fusion of an ore containing tin and copper. I will not detain you by any argument in disproof of what I regard as so absurd an idea; but I do believe that we must look to a district producing ores both of tin and copper as the most likely source of the discovery of bronze. Cornwall is such a district. But I have already stated my reasons for believing that Cornwall was not the primary source from which the bronze of very early ages was derived. No doubt exists that the Phœnicians, who were the great traders in tin between 1500 and 1200 years B.C., visited Cornwall, and purchased its tin, which they carried to the Mediterranean, and possibly also to Northern Europe; but I never heard that there was any reason to suppose that copper formed part of their commerce with Cornwall, nor indeed, as I said before, that copper was produced there in very early days. I think our friend, Professor Rolleston, who gave us so much pleasure and information at the meeting of the British Association here this year, has probably hit upon the most probable source of the early production of bronze, which he details at some length in the 7th, 8th, and 9th pages of the paper I before referred to. He first shortly discusses Cornwall, and then turns to "Khorassan;" he tells us that Strabo, who flourished at the commencement of the Christian era, and in recent time Burnes, hinted at the existence of tin in that district, and he tells us that "the late illustrious Von Baer, but twelve days before his death, in 1876, published full and authentic information upon this subject in the *Archiven für Anthropologie*, derived from a report procured by the Vice-President of the Imperial Geographical Society of St. Petersburg, Herr Semenow, as to the existence of tin, copper, and other minerals near Merv, Herat, and the Banyan Pass. This report, which the professor quotes, seems to establish the existence of rich lodes of tin and copper in that district, and they also state as a fact that many utensils of pure tin are made by the natives for household purposes. Herr Von Baer remarks: "This information makes it highly probable that the tin which enters into the composition of the many bronzes which have been found in Assyrian and Babylonian ruins came from the neighborhood of Khorassan." Professor Rolleston then goes on to mention a third locality as another and, I think, even more probable source of early bronze, namely, the region lying between Birmah and Banca. He quotes a passage from M. Mortillet, in the *Revue d'Anthropologie*, in 1875, in which he says that "it is evidently there that the origin of bronze must be sought," and he points out the abundance in which tin occurs in the peninsula of Malacca and the island of Banca, together with the copper production of the Archipelago. The Japanese and Chinese both produce copper and cast largely in bronze, even to this day. When and how in the long vista of their history did these arts begin? We know that they regard our era of 1900 years, or that of Rome preceding it by 750 years, as things of yesterday; and we know that advanced civilization had existed among them long ages before Grecian and Roman nations had any existence. Dr. Percy tells us that a book is extant, written in Chinese and Japanese, which gives a most detailed description of copper smelting in Japan, and is illustrated with not less than 100 drawings, showing the perfection to which they had carried that process in early days. The date of the book is unfortunately not given. From the translation quoted, it appears that they go through almost precisely the same processes that we and all other copper smelters of the world go through—that is, roasting and melting the ore, roasting and melting the regulus, blowing it into copper, and refining. But perhaps even more remarkable than this process, arrived at and described by the enlightened Japanese long ago, is an extract given by Dr. Percy, from an account of Hindoo Copper Smelting, written by Mr. H. F. Blanford, of the Geological Survey of India (page 387). He says : "I witnessed the process, here described, in one of the southern valleys of Sikkim Himalayas, a few miles from the Terrai. The workmen were Nepaulese, by one of whom the little mine was rented from the government." Mr. Blanford then describes the dressing of the ore, namely, pure copper pyrites, which was effected almost precisely as the same operation is performed in Cornwall, and, indeed, in Europe generally, namely, first, a separation of the best from the worst by hand ; then, after reducing the ore to a fine state, by washing in a "tye" with water, precisely as in Cornwall and elsewhere. The ore thus "dressed" is melted in a low hearth. the front wall only about six inches high, and the sides about one foot above the furnace-bed. The fuel is charcoal, and the blast is produced by bellows, made of a seamless bag of goat-skin, attached to a nozzle like a blow-pipe, made of clay ; these rude bellows were placed one on each side of the hearth, and worked by a boy who alternately loosened and tightened his grasp as he raised and lowered the bellows. The nozzle was inclined downward to within three or four inches of the furnace-bottom. Dr. Percy then proceeds to give extracts from an account published at Calcutta in 1831, of the process of copper smelting carried on at Singhana in India, which appears to be almost absolutely identical with that described by Mr. Blanford in the Sikkim Himalayas, the only difference being that the ore was first mixed with cow-dung, formed into lumps, and burnt for twelve hours in heaps ; this roasted ore was then melted at once into coarse copper, which, if the burning had been well done, would naturally be produced, probably with some regulus, which may have been overlooked by the person who wrote the account. The copper was then refined in a small vessel which received the blast of a single bellows. The notice ends with these words : "Copper smelting must have been carried on in this locality during a very long period, as the slags had accumulated to such an extent as to form a line of small hills several hundred feet in length and 30 to 60 feet in hight. There were four isolated stone bastions built on one of these artificial mounds."

I have ventured to trouble you at length with these accounts of copper smelting in the East, because, as I before stated, I think there is good ground for believing that the production of copper began there in the remotest times, and I think it is most interesting to show that the natives, although utterly ignorant of scientific metallurgy, yet nevertheless smelt ores of copper and produce that metal on precisely the same principles which prevail to this day in the most scientifically conducted works of Europe. I do not mean to assert that material differences in the appliances used do not exist ; but I do assert that the principles involved in their practice and of European copper smelters are identically the same. I have no doubt in my own mind that the systems adopted at the present moment by the Hindoo, Mussulman, Japanese, and Chinese smelters, in those far regions of the East, are precisely the same as those which their forefathers used in the remotest times. I have no doubt that the copper which went to produce the bronze with which Solomon's temple was adorned nearly three thousand years ago was smelted in the same way as that now practiced in the East, and that we may probably go back another three thousand years, to the days of Zillah's son Tubal Cain, and still with truth make the same assertion as to the process of copper smelting.

I have now dealt with the very early days of copper, the Bronze age proper, and that which preceded it. Let us now come to Roman times. We know that Æs, that is, bronze, copper alloyed for the most part, with tin, was very extensively used. We know that almost every sort of utensil was sometimes made of bronze. I doubt very much whether copper, as a pure metal, was largely used even by the Romans. I have seen thousands of Roman bronze castings, but I can not call to mind having seen one of pure copper. The reason is self-evident. All those objects of common use were cast; pure copper will neither cast sound nor fulfill the requisite conditions of hardness without being rolled or hammered; it is soft, malleable, ductile, but not hard and resistant. I think it also probable that the condition in which it left a Roman refinery, that is, like the German or Russian rosette copper, caused it to be specially unfit to be hammered, as it would be in what we call an "overpoled," and therefore not tough condition, and also very porous. Be that as it may, the fact remains that copper, as bronze, was extensively used by the Romans, and therefore that copper smelting existed at that period on a large scale. Whence did the copper come? We all know the fable that copper first came from the last but, I fear, not the brightest diamond in the British crown, the Island of Cyprus, and that it even derived its name from that island; but is it not more probable that the island derived its name from the metal? for language began with man, and we can hardly doubt that copper existed in the far East long before the Island of Cyprus received the advancing wave of Eastern civilization, bringing with it probably the name and knowledge of copper. We know as yet nothing of the copper mines of Cyprus; but we know a great deal too much of the ancient copper mines of Spain. Last year, I visited the famous Rio Tinto and Tharsis mines, and found them covered with mountains of old slags, just as the often prophesied New Zealander may some day wander over and wonder at our Swansea slag-heaps. There is good reason to believe that these workings were Roman, and no one, looking at those heaps, can doubt the great scale upon which they worked, and the skill with which their operations both below and above ground were conducted. They rejected and left unworked the low-produce pyrites, but they followed eagerly the rich veins of yellow ore which traverse those mighty deposits. I saw the wonderful northern "face" of the great "Open Cast" at Rio Tinto, compact pyrites some 80 or 100 feet deep and 1000 feet long, pierced at frequent intervals by ancient Roman galleries, following with true mining instinct the veins of rich ore. I examined critically the slag-heaps, and was astonished at the freedom of the slags, made perhaps nearly 2000 years ago, from prills. At this moment, with all my accumulated experience of copper smelting, I don't know how they made those heavy irony slags so clean. I had but little time to examine the ground, and I failed to find the remains of their furnaces. I failed also to find metallic bottoms, the famous "Eisensamen," or "iron pigs," which almost invariably accumulate in the bottom of blast-furnaces, working on ores of this nature, and which do now occur largely in the most scientifically conducted works of Germany and Sweden. Surely these "old men" knew their business! The only conclusion I could draw from what I saw at Rio Tinto was, that they must have had numerous small furnaces similar to those Eastern furnaces I have been describing, contiguous to the shafts or levels from whence the ores were raised, because the slags cover the deposit for acres in extent, and show no signs of having been driven from any one central spot, so far, that is, as my very limited means of observation went. I conclude that they must have used very low blast-furnaces, somewhat like the "Castilian furnace" of the present day, or possibly like the "Scotch hearth" of Northumberland, which is still extensively used for smelting lead ore, and which is little more than an ordinary blacksmith's hearth; such a furnace would probably be less likely than any other form of blast-furnace to produce "Eisensamen," or "metallic pigs." It is also probable that they roasted the ore and regulus in heaps, because the Spaniards do so at the present day, and have done so from time immemorial, for the purpose of rendering a portion of the copper soluble, and thus obtaining it by lixiviation and subsequent precipitation by iron. It is by this process that the present great copper production of Rio Tinto, Tharsis, and Mason & Co. is effected; but in Roman times, it is plain that the rich ores alone were worked, and that the copper was obtained by smelting; otherwise, the enormous masses of slags which we see could have had no existence. I am confirmed in this belief as to Roman copper smelting by the process adopted at the Ocker Hütte, in the Hartz Mountains, where ore of a very similar character to Spanish pyrites is produced from the great Rammelsberg mine, which is said to have been continuously worked from times quite as remote as the Roman era. That ore is a pyrite rich in iron and sulphur, but poor in copper. It is, or was up to a recent date, burnt in heaps, and then smelted in low blast-furnaces, so low that the ore is charged from the floor of the works, no stage being used, as is usually the case in blast-furnaces: the resulting regulus is, or was, burnt again and again in heaps, and again and again melted in low furnaces. I believe little or no change took place in the process of copper smelting at the Ocker Hütte from the remotest times up to the date of which I am speaking, some thirty-five years ago, and that we have there a relic of the practice of those bygone ages; by no means a bad one for the class of ores and fuel they had to deal with.

No doubt the Romans obtained their supplies of copper from various sources besides Spain. There appears to be little evidence as to the working of copper mines by the Romans in England. Dr. Percy, however, quotes M. Albert Way and Mr. Franks, two eminent archæologists, as having informed him that lumps of metallic copper, more or less rounded, have been discovered in different parts of the country, but always in association with articles of bronze. He examined one of these, and found it to be practically pure copper. He also says that Pennant describes a cake of copper found at Caerhun, or Caer-hên, the ancient "Conovium," near Conway; it weighed 42 pounds, and resembled a cake of beeswax; the diameter at the widest part was 11 inches, and the thickness 2¾ inches. On the upper surface was a deep concave impression, with the words "Socio Romæ," and across them the word "Natsol." This would seem to indicate that a Roman co-partnership existed, and that the partners received their dividends in kind. Dr. Percy supposes that the copper came from ores raised at Llandudno, which were smelted *in situ*. This, I believe, is almost a solitary instance of Roman copper in England, although they had abundance of bronze; but whether imported or produced here, we know not.

What happened in the dark period which followed the withdrawal of the Romans from Britain I am unable to say, nor do I believe that any authentic record exists. We must remember the condition of England at that time. Hume thus describes it: "The private and public edifices of the Britons were reduced to ashes; the priests (Christian priests) were slaughtered on the altars by those idolatrous ravagers; the bishops and nobility shared the fate of the vulgar; the people, flying to the mountains and deserts, were intercepted and butchered in heaps; some were glad to accept of life and servitude under their victors; others, deserting their native country, took shelter in the province of Armorica, where, being charitably received by a people of the same language and manners, they settled in great numbers, and gave the country the name of Brittany." Hume quotes from Bede, Usher, and Gildas to support his assertions. We must remember that the period which succeeded the withdrawal of the Romans was one of almost constant warfare. It is not until the time of Elizabeth that I can give any reliable account of what took place in England so far as copper is concerned. Dr. Percy mentions that Edward III., in the 15th year of his reign, granted the right of working the copper mines of Skildane, in Northumberland, and the copper mines of Alston Moor, in Cumberland, and the copper mine near Richmond, in Yorkshire, on payment of a royalty of one eighth to himself, and one ninth to the lord of the soil, to a company of adventurers, among whom was his brother Richard, Duke of Gloucester, and Henry, Earl of Northumberland. In the reign of Elizabeth, there was a rich copper mine at Keswick, in Cumberland, of which that queen deprived the Duke of Northumberland on the ground that it was a mine royal. It was reported that 4000 men were employed at that mine, but this is probably a great exaggeration. According to Camden, much good copper continued for a long time to be made at Keswick and Newland; but Webster, in 1671, wrote that now "the work is quite left and decayed, yet I am informed that some do now melt forth as much good copper as serveth them to make half-pennies and farthings." I beg especially to direct your attention to this smelting at Keswick, in Cumberland, because I think there is no doubt from the records brought to light by the laborious and intelligent researches of our fellow-townsman, Lieut.-Col. G. Grant Francis, that the first smelting-works in South Wales was built and worked by men from Keswick. I am very glad indeed to bear testimony to the great interest and value which attach to

Colonel Francis's work, of which I am about to avail myself to give you a short account of how copper smelting began in this district. I allude, of course, to the work published by Colonel Francis in 1867.* It is not my purpose to give the history of copper smelting down to the present day; those who desire to go into the details of that history will find them fully set forth in Colonel Francis's admirable work; but what I desire to do is, so far as I am able, to trace the history of the process known as the South Welsh process of copper smelting, which really now is the dominant process of the world. I remember well that Colonel Francis announced to me before he published his letters in 1867, that he had discovered that our Welsh copper-smelting process came from Germany. I at once told him, and I still retain that opinion, that such could not be the case, inasmuch as nothing analogous to it existed in any part of Germany, even down to our time. I think we were both in part right. The evidence Colonel Francis has discovered puts it beyond a doubt that Germans were largely engaged in the Keswick smelting; but there is no tittle of evidence that I can discover that they brought our reverberatory process with them from Germany. In point of date, the story begins with a patent granted by Queen Elizabeth, in 1564 (page 29), to Thomas Thurland, Junior, of the Savoy, and Daniell Hogstetter, a German, giving them "power and authority to search, dig, try, rost, and melt all manner of mines and ores of gold, silver, copper, and quicksilver in York, Lancaster, Cumberland, Westmoreland, Cornwall, Devon, Gloucester, and Worcester, and the Principalities of Wales, as well within her Majesty's own grounds as others, on payment of a royalty." In the same year, a patent was granted "to William Humfrey, and Christopher Shutes, a German, with similar powers within England, and the English pale in Ireland, except the places afore granted." Under the first of these patents, no doubt, the working and smelting at Keswick were carried on. Seventeen years later, in 1581, we find a letter from Mr. George Nedham, to Sir Francis Walsingham, setting forth in considerable detail the operations which were carried on under the direction of one Jochim Gaunse, Ganse, or Gans, for his name is spelt in these three ways. This letter is of a most interesting character, and contains, I believe, distinct indications of the first introduction of the system of copper smelting which has been ever since that date so largely practiced in this district, and which is now more or less adopted in almost every important copper-producing district of the world. I gather from this letter that the Keswick Works were managed by Mr. Daniell (possibly the Mr. Daniell referred to was Mr. Daniell Hogstetter) and Mr. Stemberger up to 1581, when Mr. Jochim Gans went there; that their practice had been to roast and smelt the ore and regulus repeatedly; as many as sixteen and even twenty-two fires are mentioned; half of these were roastings and half meltings, and the time occupied was as many weeks as fires. It is pretty certain that the roasting was done in heaps; for by no other means can I conceive it possible to roast and melt so many times without producing copper. Nedham says (Par. 3, page 20): "And further, the said Jochim doubteth not but after he hath rosted and smolten 3 or 4 saies of o'r copper ure in the great worke, after such manner as he hath devised since his coming from Keswick, to attaine to such further knowledge of the nature of all o'r copper ures in Cumberland and Westmoreland, that he shall be able to kill all corrupt humours in them and thereby to bring out more copper than heretofore hath byn and with lesser charge than is above written." Now here we have it distinctly stated that Jochim Gans *devised this manner* of working *after* he was at Keswick, and it is plain that he did not bring the new "*manner*" with him. At the bottom of page 23 this passage occurs: "The number, nature, and propertie of which ix hurtful humours being wholly unknowne to Mr. Daniell and his Sonne or to any other of the Dutch workemen w'ch have bin sente from Germany to the mynes, that have bin in our copper ures, has bin the onely cause of the unreasonable charge and long tyme spent before they could make of these ures perfect rough copper; which copper after the order used in tymes past by Mr. Daniell and his Son thei never could nether yet can make under xxii tymes passing thro the fire and xxii weeks doing thereof and sometyme more." "But now by Mr. Jochims order of working we can—by once rosteing and once smelting the ure (w'ch shall be done in the space of three days), the same copper ure shall yield us black copper and copper stone which nether Mr. Daniell nor his Sonne could or yet can do under xvi times passing through the fire and xvi weeks in doeing thereof, and further in once rosteing and once smeltinge the same black copper and copper stone again, which shall be done in two days after Mr. Jochims order of workeinge, I will bringe the black copper and copper stone into perfect rough copper, which Mr. Stemberger cannot make under xxii tymes passing through the fire and xxii weekes in doinge thereof and sometymes more." Again at page 25, paragraph 4, we have the following, which distinctly proves reverberatory calcining, "but by stampinge the copper ure into powder and by rostinge the same powder after Mr. Jochims order before it be smolton, and then letting water passe through the same roasted powder, the water doth not only carry the vitriall from the powder or ure, but also carries with it the burnt sinder of the sulphur." Now these extracts show the nature of the improvements introduced by Jochim Gans, and I know of no other way in which such effects could have been produced except by the reverberatory calciner and furnace. It must be observed that Nedham reports that by once roasting and once melting, black copper and copper stone (regulus) were produced in three days. Such a thing I believe to be only possible by using reverberatory calciners. Again he states that in once roasting and once smelting, this black copper and regulus can be made into perfect rough copper in two days; this could only be done by the reverberatory furnace. Both these passages prove to me conclusively that the "manner" or "order" of working devised by Jochim Gans at Keswick was the reverberatory furnace process. He was doubtless a German, but he did not bring the process from Germany. I am not aware that there is any positive proof of the first use of the reverberatory furnace for copper smelting; but the extracts I have read contain such strong inferential proof that, until I hear something of a more certain character to the contrary, I shall give Jochim Gans the credit of having devised that most important "manner" of copper smelting at Keswick in Cumberland, in 1581–82, just three hundred years ago. Jochim Gans at the same time proposed to wash out sulphate of copper from calcined ore, and Nedham, in his report to Lord Walsingham, devotes much space to this plausible proposal. The same idea has occurred to many a man since his time, and in each case in practice it has proved as unprofitable as no doubt it did three hundred years ago; for we hear no more of poor Jochim Gans or his sulphate process.

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* *The Smelting of Copper in the Swansea District, from the Time of Elizabeth to the Present Day.* By Major Grant Francis. Not published. Swansea. 1867. 8vo, 126 pages. (Only fifty copies printed.) For announcement of the Second Edition, see ENGINEERING AND MINING JOURNAL, February 5th, 1881, p. 95.

The next notice we have which I think it worth while touching upon is contained in a correspondence between Ulrick Frosse and His Right Worshipful Thomas Smith, Esq., Principal Customer of London, at his house in Fanchurch street, in London, 7th July, 1584, therefore two or three years later than the extract just given. Customer Smith was a holder of one quarter part of a share of $\frac{1}{14}$th in the "Mines Royal Society" in 1580—$\frac{1}{56}$th part. Ulrick Frosse is mentioned by a Mr. Carnsewe as superintending a mine in Cornwall, and I infer that "he was a Cumberland man, because Mr. Carnsewe proposes that he should take such men as he is now acquainted with of our countrymen, and work in competition with certain German miners whom Mr. Weston had introduced at 'Trewoorth, near Perin Sandes,' Cornwall." On the 21st July, 1584, Thomas Smith writes to Ulrick Frosse, saying that Mr. Weston is going to Cornwall through Wales, and that he will take measures for transporting the copper ores to the "new melting-house at Neath, in Wales, which house, I understand, is ready, and we have taken order here that against he shall be ready to make copper he shall have from Keswick one of our copper makers, with an under melter and the Dutch carpenter, for a time, to serve and ready him in these causes." Now this fixes the exact date of the commencement of copper smelting in South Wales, namely, the autumn of 1584, and it shows that the skilled workmen came from Keswick. As the carpenter is specially called a Dutchman, I think it follows that the "copper maker" and "under melter" were not Germans. It is possible that the Dutch carpenter was a skilled mill-wright, as, later on, water-power is mentioned, probably in connection either with blast or stamping machinery. In the latter part of the same letter, Ulrick Frosse is told that "about Michaelmas next he shall go bye at Neath to take charge of our melting-house and things there." Frosse writes to Carnsewe on the 3d August, 1584, from Cutbert Parish, in Cornwall, a letter which seems to indicate that they had been trying to smelt in Cornwall, and had got the regulus and slag mixed up together. On the 9th June, 1585, Frosse writes from Neath to Mr. Carnsewe. He advises having sent samples of their stone, or regulus, and copper, and complained he was waiting for more and richer ores from Cornwall, and wanted "to repair his water-weere and furnesses." On the 4th July, 1585, Frosse writes to Denham that they "had founde out a waye to melte 24 C of owre everye daye with one furnas, the Lord be thanked, and if we may have owre enough from yo'r side, we maye, with God's helpe, melte with tow furnases in 40 weeks 560 tonnes of owre, having reasonable provision made for it; desiring yow from hence forwarde to sende such owres as yow have with as much speed as may be, not caring what owre it is." It appears, therefore, that, within less than a year after the works were started, Frosse felt master of the position, and was able to deal with whatever ore they sent him, but they had not yet refined copper. On the 7th March, 1586, Ulrick Frosse wrote to Mr. Carnsewe: "Wee looke dayley for the copper refiner from Keswicke, and have in readines as much copper roste and blake copper as will make a 20 tonne of good copper." He reported in the same letter that he "could melt in 7 hours 24 c. of owre, with 8 or 9 seks of chare coles and 8 horslod of sea coles; melting many sorts of owres to gither is the most proffet and will smelt a greattayll souner."* Now this passage shows that they had so increased their melting as to do upward of 3 tons per 24 hours, and that they could take any kind of ore, but, above all, it proves that they were using reverberatory furnaces, because "sea coles" are suitable for such furnaces and not for blast-furnaces. The charcoal was probably mixed with the coal to prevent its binding too strongly, just as we now use "free" coal. The charge of 24 cwt. was curiously enough the same which was used by works up to a recent date. My object in giving these extracts is to show, not alone how copper smelting commenced in South Wales, which is of great local interest, but also how the South Welsh process of copper smelting, which may be said to be at this moment the ruling process of the world, began. The first introduction of copper smelting in Lancashire seems to have been in 1717, near Warrington. I think these extracts clearly prove that in 1581 Jochim Gans "devised a manner" of working copper ores at Keswick, which enabled him, by once roasting and once melting the ore, to produce black copper in three days from powdered ore, and I know of no other system than reverberatory furnaces by which that result could be attained; and we find Ulrick Frosse four years later, at Neath, with all the experience of Keswick, advising his employers that he had found out a way to melt a considerable quantity of ore per day in one furnace, "the Lord be thanked," and that he could deal with all kinds of ores, using sea-coal as fuel, which shows, beyond doubt, that he had improved Jochim Gans's reverberatories and was using them. This, I think, is the history of the invention by one man, and practical working out by another, of the South Welsh system of smelting copper. And now I naturally come to the consideration of that system, both in comparison with the European and Asiatic systems, and on its own merits.

When I use the term South Welsh system of copper smelting, I carefully avoid the term "principle" of copper smelting, because the same "principle" must be the base of all copper smelting. The ends are the same, but the means of attaining them are different. The difference lies in our use of reverberatory furnaces both for calcining and melting, while the other systems of the world depend (or perhaps more correctly depended) on roasting in heaps and melting in blast-furnaces.

Let us then first consider the processes which must be gone through in either case to produce copper from its ores. Now, what are its ores? If you turn to a work on mineralogy or chemistry, you will find an infinite variety of ores and combinations of copper, 25 at least; but in practice copper occurs in nine cases out of ten in combination with sulphur. In by-gone times, large quantities of carbonates came to us from Australia and Chili. Even now, the latter sends us occasional cargoes of green ores, containing carbonates, silicates, chlorides, oxides, and other combinations of copper; but these ores unfortunately bear but a small proportion to the ores containing copper in combination with sulphur. The same is the case in other parts of the world, and we may therefore direct our attention almost exclusively to the smelting of sulphide of copper in combination with sulphide of iron, earthy matters, and every known and unknown metal and mineral in creation. In all copper smelting, the first object must be to lose as little copper as possible in the slag, and to make the fusion easy. To this end, the copper smelter anxiously considers the varying nature of his ores. Some contain large quantities of sulphide of iron; these he takes care to roast or calcine highly, in order to obtain oxide of iron wherewith to flux the siliceous matter of other ores and to produce a regulus sufficiently rich in copper, his standard in that respect being from 30 to 35 per cent. Some ores containing much earthy matter he finds will not pay for calcining; that is, if he has plenty of ores of the first-named class at his command. The extent to which he calcines his ores depends on their nature and the proportion which one sort bears to the other, his object being to produce in his first melting a regulus, that is, a combination of copper, iron, and sulphur, of not less than 30 per cent or more than 35 per cent. Not less than 30 per cent, because if less, the subsequent processes are rendered more costly by the increased quantity which has to be treated; not more, because each prill which is held in mechanical suspension in the slag is richer in copper, and thus increases the loss, while there may even be some danger of getting oxide of copper into the slag. Now, whether this process is conducted in a reverberatory calciner, in a Gerstenhöffer, in a muffle (of which more hereafter), or in heaps as before explained, the objects to be attained are the same in all cases. The merits of the different systems of calcining or roasting may be shortly stated thus: The most ancient, namely, roasting or burning in heaps, is the least costly, provided the ore is sufficiently rich in sulphur or bituminous matter, as in the case of the Mansfeld Kupferschiefer; but it is not applicable to ores poor in sulphur, and in any case it is very tedious, occupying weeks, or even months, and therefore necessitating enormous stocks of ore in comparison with the quantity treated. The South Welsh calciner, on the other hand, is rapid in its action, never exceeding 36 hours, and for ordinary ores 12 hours, while the quantity treated is considerable and the cost of coal and wages consequently small. Our large calciners at Hafod treat 14 tons each charge, the time of course depending on the nature of the ore we are operating on. It is, I may assume, well known to all whom I am addressing that calciners are long and wide reverberatory furnaces; ours are 28 feet long by 13 feet wide (inside measurement), with a comparatively small fire-grate at one end; that the ore is spread evenly over the bed of the furnace, and is occasionally stirred or "paddled," that is, lifted with a flat, spade-like tool, so as to expose fresh surfaces to the action of the flame, which passes in rolling waves along the roof, a stratum of atmospheric air intervening between it and the ore, which supplies the necessary oxygen to combine with the sulphur, arsenic, and other volatile minerals, which are thus enabled to form their respective acid combinations and to pass off in the gaseous form, while the iron and other metals become oxidized. This calcining furnace is simple and under complete control. Any ore can be treated in it, and the process can be arrested at or pushed to any desired point. In this furnace, the sulphur gases are wasted, because they are diluted by the excess of atmospheric air present in the furnace, and they are at the same time rendered impure by admixture with the products arising from the combustion of the coal used for heating the calciner. It has, therefore, never been practicable to utilize the sulphur gases of ordinary calciners for the manufacture of sulphuric acid. In some copper works, calciners with double beds are used. I have tried them, but have found no advantage to arise from them, while they are more costly both in erection and repairs.

I have now to notice calciners adapted to the production of strong and pure sulphur gases for conversion into sulphuric acid. These are of three kinds, namely: Kilns in which the material is burnt in pieces of the size of road metal; the Gerstenhöffer calciner, in which it is burnt as powder; and the Muffle calciner, which is worked by transmitted heat. I believe other systems have been proposed, but I am not aware that they have been proved to be of practical value.

The Kiln system of burning is applicable only to material very rich in sulphur, say 20 per cent and upward, and in a rough state. It is the system universally adopted in alkali and sulphuric acid works for the treatment of pyrites rich in sulphur and iron and poor in copper. I can not state the exact limits within which this system is applicable; but I know of instances in which ore as low as 23 per cent of sulphur has been burnt. This system is at once the cheapest and most complete wherever it is applicable.

I next come to the beautiful invention of Mr. Moritz Gerstenhöffer, and now known by his name. This invention was brought to my notice by the late Mr. Herrmann in 1865. I at once saw its practicability, and caused two experimental furnaces to be built. They were found successful. We purchased the patent, and shortly afterward erected 43 calciners, more than sufficient to treat all our ores and regulus which were sufficiently sulphurous to admit of being thus dealt with. After fifteen years' experience, I can say Mr. Gerstenhöffer's invention is still a success. The principle upon which it is based is the same as that of the alkali-maker's kiln, namely, that the heat of the furnace should be maintained by the combustion of the sulphur of the material under treatment, and that no more atmospheric air shall be admitted than is necessary to maintain such combustion without fusion of the material, while the resulting sulphur gases shall be strong enough to be available for the sulphuric acid chamber. The alkali-maker was limited to the use of rough material. Mr. Gerstenhöffer solved the problem of using fine material. He constructed a vertical furnace 14 feet high, 4½ feet wide, 2½ feet deep (inside measurement); he placed across it fire-brick bars of triangular form, presenting one flat surface to the horizontal plane, and so arranged in rows above each other that the edges of the higher triangle should coincide with the center of the triangle next below. He heated his furnace to a good red heat by a coke fire temporarily lighted in the lower portion, and when at full heat he withdrew the coke and fed mechanically, through slits in the top, a constant and regular stream of the sulphurous material under treatment which, falling on the highest rows of cross-bars, formed a cone on each, and then fell on to the next bar beneath, and so on until each bar of the 70 contained in the furnace received its full charge, while the sulphur in both the falling material and that which lodged on the bars became ignited and burnt by aid of the atmospheric air admitted through holes in the front of the furnace, arranged just above the top of each cone of ore, thus keeping up the heat by the combustion of its own sulphur, and giving off pure and strong sulphur gases, sulphurous with some sulphuric acid. By this simple and beautiful arrangement, the problem of burning fine sulphurous ores and regulus, which had puzzled many a wise head, was successfully solved. I hope from the description I have given that the operation will seem plain and clear to the minds of my hearers, probably far simpler than we have found it in practical working; for I may say that we have only just arrived at what I consider satisfactory working; and when I say "we," I desire to acknowledge the zeal and intelligence which Mr. William Morgan and his son, Mr. William Edward Morgan, have displayed in perfecting this system. For example, I see that when I gave evidence before the Commission on Noxious Vapors, in April, 1877, I produced figures showing that we had during the previous year condensed and made into sulphuric acid 37·93, say 38 per cent, of the sulphur contained in the whole of the ores we treated; while from figures just furnished me by Mr. Morgan, based on calculations precisely similar to those contained in my answer (10,906), I find that during the year ending July, 1880, we condensed and made into sulphuric acid just 47 per cent of the sulphur which was contained in all the materials treated at the Hafod Works, showing an improvement of about 25 per cent. Again, in that evidence I stated our consumption of niter at 4·53 per cent upon our oil of vitriol, whereas it has now been reduced to 3·3 per cent, mainly by the use of the Glover and Gay-Lussac towers. I remember when it was 7 per cent; and when our then manager, upon my complaining of this excessive consumption, assured me, and proved by abstruse chemical calculations, that it could not be reduced, my reply was, "Never mind chemical formulæ; if you can't reduce it materially, I shall take it in hand myself." We are still a long way off the niter consumption of kiln-made acid, which does not exceed 1·3 per cent. I despair, however, from various causes, of ever reaching that low consumption. When I state that we condensed last year 47 per cent of our sulphurous gases, and lost 53 per cent, it must, of course, be understood that I refer to the whole products we treated, many of which are unsuited to the Gerstenhöffer, or any other close calciner. That loss is chiefly due to the melting furnaces and to the last process of roasting white metal into copper. That metal melts at so low a temperature that it is extremely difficult to calcine without running it together, unless an excess of air is present. In a lecture of this nature, which is intended to give a general and popular rather than a scientific account of copper smelting, it will not, I think, be expected that I should dwell at greater length on this or any other single process. Those who desire to see an account of the working of the Gerstenhöffer calciner in more detail, will find it in the evidence I gave before the Noxious Vapors Commission in 1877. It may be interesting to state that we last year condensed 3666 tons of oil of vitriol (concentrated sulphuric acid), which would otherwise have gone into the atmosphere, and been wasted.

I now come to the third and last system of calcining furnaces adapted to the manufacture of sulphuric acid from copper ore or regulus, namely, the "muffle calciner," which, in external appearance, is very much the same as an ordinary copper calciner of the old form; internally, however, it differs considerably, since the material under treatment is inclosed in a chamber of fire-brick, constructed by arching over the inner space in such a manner as to cause the products of combustion to pass over and under the ore-bed, and transmit the heat through the fire-brick. By this means, the sulphurous gases are obtained free from admixture with the coal gases, and no more atmospheric air is admitted than is necessary for the production of sulphurous acid and the oxidation of the iron, etc. I have no practical experience of muffle calciners, because I never thought well of them, owing to the expense of fuel consequent on working with transmitted heat, and the dilution of the sulphur gas when the door is taken down for stirring. The first difficulty is got over at Mr. Lambert's works by using a muffle calciner heated by the waste heat of the smelting-furnace; but when we consider the varying intensity of the heat given off at different periods of the ore-furnace charge, ranging from almost none at all at the period of skimming and charging up to the highest temperature during the melting process, I can not doubt that much irregularity must occur in the calcining process which must militate against the regular working of the chambers, especially when joined to the inrush of atmospheric air when the calciner doors are down for stirring. I have seen the muffle calciners at Mr. Lambert's, and have read his evidence and that of Mr. Fenwick Allen, the manager of Messrs. Newton Keates & Co.'s works in Lancashire, where, as well as at the St. Helen's works, muffle calciners are used, heated on the Siemens system. Unfortunately, neither of these gentlemen goes fully into the question of the profitable working of muffle calciners; but I think I am justified in saying that they do not appear in several respects to give results equal to the Gerstenhöffer system. In Mr. Allen's answer to question 11,646 of the Noxious Vapors Commission, he says: "We diminish the escape by condensing the whole of the acids given off in the calcining process, and at the very outside it would be from 30 to 40 per cent of the total sulphur given off in our works." I should have been glad if Mr. Allen had been able to give the committee, as I did, an accurate debtor and creditor account of the whole of the sulphur which entered the works. Again, he was unable to inform the Commission (11,660) what the percentage of niter used at his works is; but he says generally (11,658) that the gases are very dilute, and that they require three times as much niter as in ordinary kilns; and he also says (11,657) that the sulphuric acid costs 5s. more than if made from pyrites bought and burnt in kilns. Mr. Lambert's evidence as to the results of muffle calciners is even less favorable. I think I have now pretty nearly exhausted the subject of calcination, and may proceed to smelt my ore.

In considering the question of melting the calcined ore, I think we ought, in the first instance, to pass in review the two systems of reverberatory and blast-furnace smelting—"South Wales against the world!" Each system has its advantages and disadvantages. Let us weigh them. The blast-furnace is slightly, very slightly in most places, more economical in the cost of fuel, and it undoubtedly, and in all cases, produces a cleaner slag; but its working is much more complicated, and it has a constant tendency to reduce the oxide of iron contained in the calcined ore into metallic iron, and thus to produce a mass of infusible matter at the bottom of the furnace, which, in no long period, causes the entire or partial destruction of the furnace, according to the arrangements made beforehand to extract it. Even in the best managed continental works, I have positive proof that these so called "iron sows" are produced; in fact, they are an almost unavoidable incident of melting calcined copper ores in blast-furnaces, especially high blast-furnaces, owing to the partial reduction of oxides of iron by the ascending carbonic oxide before it reaches the melting-point, where it would be able to combine with the silica, which we must assume has been provided for it. It has, I am aware, been proposed to get over this difficulty by taking off the gas a few feet above the melting-point; but no great success can have attended this, from the fact that "iron sows" are still produced in considerable quantities in the best managed continental works. Another great draw-back to the use of the blast-furnace is, that it can only treat a comparatively rough mixture; much fine ore would soon cause it to "gob" or choke. The consequence is, that resort is had to slags to keep the furnace open, if rough ore can not be obtained, even if the slag does not require remelting. I know of a case in which thousands of tons of slag are thus uselessly melted. When lead ore is melted in blast-furnaces, it is possible to agglomerate it in the calciner so as to cause the furnace to "drive" well; but copper ore would require so high a temperature to agglomerate it, when sufficiently calcined, that it would be more economical to carry it a trifle farther and melt it in a reverberatory furnace at once. In blast-furnaces, for the above reasons, I doubt whether ores could be dealt with, as they arrive from all quarters of the globe, varying enormously in their constituents and characteristics. Nothing in reverberatory copper smelting needs greater care than the formation of a proper mixture for the ore-furnace; but the problem becomes vastly more complex if the ore-furnace be a blast-furnace.

I said that the blast-furnace uses less fuel than the reverberatory. Roughly, I believe, the case stands about as follows: A blast-furnace uses from 15 to 25 per cent of coke, calculated on the quantity of ore smelted, according to the nature of the ore and the furnace; take it at 20 per cent. A reverberatory uses, say 45 per cent of coal; but coke is about 2½ times more costly than coal, therefore the expense of the blast-furnace would be as 50 to 45 of the reverberatory. If steam power is used for the blast, it makes the case of the blast-furnace so much worse, unless the waste gases can be utilized to generate steam; but if fuel has to be transported to a distance, although the freight on coke is more than on coal, the balance may slightly incline in favor of the blast-furnace.

I also said that a blast-furnace produces a cleaner slag than a reverberatory furnace. I believe that such is invariably the case, owing to the higher temperature at the melting-point, which causes the slag to be more fluid, and thus permits the heavy regulus to pass more easily through the slag; the deep well of the blast-furnace also assists in the last-named effect. I estimate the difference between blast-furnace and reverberatory slags to be about one fourth per cent, equal in money to about 3s. per ton of ore. As to the item of wages, I can not speak positively, because so much must depend on the nature of the ore and the furnace; but in all cases with which I have had to do, the blast-furnace cost is in excess of the reverberatory. There is one other considerable disadvantage in smelting in a blast-furnace, namely, that from the same calcined ore a reverberatory furnace will produce a much richer regulus than a blast-furnace; the former is an oxidizing, the latter a deoxidizing furnace. During the exposure of the ore on the bed of a reverberatory furnace, calcination goes on continuously, sulphur and the sulphuric acid partially formed in the previous calcination passing off. We found, on careful trial, that during the smelting of calcined ore in the ore reverberatory furnace, 13 per cent of the original contents of the ore in sulphur were driven off. I have no similar data as to what sulphur is driven off in the blast-furnace. The smoke issuing from blast-furnaces proves beyond doubt that some is sublimed; but from the deoxidizing condition of the furnace, all the sulphates must be reduced, some to sulphurous acid probably, and some to sulphide of copper. As a fact, blast-furnace regulus is always coarser than reverberatory regulus, which means that more expense has to be incurred in the subsequent processes.

The reverberatory furnace is a simple and easily worked furnace, forming no metallic bottoms until the copper stage is reached, and capable of dealing with all ores, as Ulrick Frosse found out three hundred years ago. Whether calcined ore is melted in blast or reverberatory furnaces, the same results ensue, namely, the earthy matters (chiefly silica) originally contained in the ore combine with the sesquioxide of iron to form a slag, while the sulphur, purposely left in the calcined ore, forms sulphides of iron and copper, which, being of greater specific gravity, sink through the slag, separating themselves more or less completely from it, according to the nature of the slag and the temperature at which it is melted. For this cause, the copper smelter must be careful so to combine his ores as, on the one hand, not to form too stiff or quartry quartz, a slag which hinders the operation of melting, and prevents the regulus from sinking freely through it; and on the other hand, too heavy a slag, which, while it may melt easily, is so nearly of the same specific gravity as the regulus as to cause the separation to be imperfect on that account. He must also be careful not to produce too rich a regulus, because the perfect separation of regulus and slag is next to impossible, and each prill of regulus which remains mechanically suspended in the slag carries with it more copper if rich than if poor. As I think I before said, we do not like to push our "coarse metal" or ore-furnace regulus beyond about 33 per cent of copper; it contains about 23 per cent of sulphur, and the remainder iron, arsenic, and other impurities, resulting from the original ore. I see Le Play gives "coarse metal" as containing 29·2 per cent sulphur. According to our experience, it does not usually contain more than 23 per cent. The ore-furnace slag consists chiefly of silicate of protoxide of iron and silica in suspension. Dr. Percy's concluding observations as to the reactions which take place in the ore-furnace are concise and clear; any one who desires to study them in detail can do so by referring to the 345th page of his work; indeed, the whole of the chemical changes which occur in copper smelting are set forth with admirable terseness and precision.

Before quitting ore-furnace slag, there is one point I should like to mention, which may be of practical value to copper smelters now and hereafter. Whatever loss of copper occurs in this slag arises from prills of metal which have not had time or were not sufficiently large to settle or fall through the slags while in the furnace, and are consequently skimmed out with the slag. These prills, to a very large extent, fall through the fluid mass after it is skimmed into the sand molds. It will always be found, if the slag is sufficiently fluid, that the bottom contains far more of these prills than any other portion of the slag. The practice is to drive these slags out on iron wheelbarrows and place them to cool in a courtyard; when cool, they are broken through, and the portions most prilled are returned to the ore-furnaces. Soon after I first interested myself with copper smelting, now thirty-seven years ago, I observed that the large irregular masses of slag which resulted contained visible prills of regulus in the lower three or four inches only, while a large proportion contained no visible prills, and were not worth the cost of re-smelting, except from their association with the richer portion. This led to much poor slag being melted and much rich slag being thrown away, from fear of increasing the bulk too greatly to go back. Upon one occasion, I saw a slag broken through, which contained a large cavity in the center and a thin plate of slag at the bottom, sides, and top. I at once sought the explanation, and found that the center of that slag (and almost all slags are the same), when driven out to the court, was still in a liquid state; that by some accident a corner had been broken off, and that the liquid center had run out, leaving a thin hard crust round the bottom, top, and sides. Here was exactly what I wanted, and since that day—now some five and thirty years ago—no more heavy masses of slag have been made at our works. I at once caused the slags then on the bank to be "tapped," by striking a hole with a pointed sledge into the center of the bottom end as they lay on edge, and then another at the top (or striking off a corner), when the fluid center ran out, and left me a thin plate at the bottom, completely separated from the rest. This is almost invariably so much prilled as to be worth remelting; if it is more than usually so, the "runner" is also tried and melted; and in stiff slags, metal is sometimes found in the "top," which is then also remelted. For some years, I caused an account to be kept as nearly as might be, of the metal saved by this system, and the result was so satisfactory that I felt justified in stealing the copper to make the Sketty Church bells, the copper in which, I may now confess, was never paid for: I took it as an honorarium for my little invention.

By this melting of calcined ore, whether in reverberatory or blast-furnaces, we have obtained two products: first, a regulus of copper, iron, and sulphur, which contains about 33 per cent copper and 23 per cent sulphur, and the remainder iron and other metals; and secondly, slag, which contains all the so-called earthy minerals originally present in the ore, with sufficient oxide of iron to combine with and fuse them. This slag is thrown away, and at once relieves the copper smelter of about two thirds of the bulk he has to treat. The regulus of 33 per cent copper with sulphur and iron remains to be dealt with.

Whether in South Wales or on the continent, or in far-off India and Japan, this regulus must be roasted or calcined, to drive off the equivalent of sulphur combined with the iron it contains, and to convert the latter into an oxide—Le Play says "sesquioxide." Abroad, this was burnt in heaps; here, it was first granulated by running it from the ore-furnace into deep pits, filled with water, after which it was calcined in our large reverberatory calciners for thirty-six hours, which time was found sufficient to drive off enough sulphur to afford oxygen for almost the whole of the iron present, leaving sulphur enough to combine with the whole of the copper, when melted, and to produce pure sulphide of copper, which we term "white metal," containing from 72 to 75 per cent of copper. These calciners contained each twelve tons, and were charged with four tons at the flue end every twelve hours, while four tons were withdrawn from the bridge end, nearest the fire; simultaneously, the center charge of four tons was moved to the bridge end, and the charge at the flue end, which had been working twelve hours, was moved to the center. Thus each charge of four tons remained in the furnace thirty-six hours, while the furnace got through four tons every twelve hours. That practice is now wholly abandoned in favor of the Gerstenhöffer before described. We now run the ore-furnace regulus into molds, grind it, and pass it through a ten or eleven-hole sieve, and then treat it in the Gerstenhöffer. We find that from ore-furnace metal thus treated we drive off nearly one half the sulphur in that process, leaving behind about 12 per cent of sulphur out of 23, still combined with the copper, or rather, perhaps, to be combined with it, to the exclusion of the iron in the metal furnace melting. We find it better not to push this calcination too far, because it is always wise to have rather too much sulphur present in the calcined metal, so as to be able, by the addition of ore containing copper in combination with oxygen, such as carbonates, oxides, and silicates, to hit the exact mark we desire in the metal or regulus produced in the metal furnaces. If it is to be roasted forward directly into copper, we produce "white metal;" but if to be put through the "best select" process, then the metal produced in the metal furnaces is kept slightly back; that is, below "white metal," the whole of the iron not being reduced; this metal is then roasted, or slowly melted down in the metal furnace, by which means an impure metallic copper bottom is produced, which contains many of the impurities with which the ore was originally contaminated, while the sulphide of copper floating above this metallic bottom and easily separated from it is comparatively free from impurities. This process is, however, incapable of so completely freeing copper from those impurities as to render it always fit for best brass purposes.

I must now return to the metal furnace melting, which with us is always effected in reverberatory furnaces. I believe they are now almost universally adopted for concentration in Germany and elsewhere on the continent as well as in America and Chili. I remember well when not one reverberatory copper furnace existed in Germany for copper smelting; the concentration of copper regulus and refining in blast-furnaces is now so thoroughly antiquated that I need scarcely notice it. As our calcined copper metal contains so much oxide of iron, it is necessary to add siliceous matter to form a suitable slag: ores rich in silica, and, if possible, containing copper in combination with oxygen, as before mentioned, are the most desirable for this purpose. The products of this second melting are "white metal," almost pure sulphide of copper of 73 to 75 per cent, and metal slag, which Le Play gives as 33·8 silica, 56 per cent protoxide of iron, and 2·9 per cent copper: this slag goes back to the first melting. "White metal" may be regarded as the standard product of our second melting. If a lower regulus is produced, an intermediate or second metal melting has to be gone through, involving extra cost; if the point of white metal is passed, a portion of the copper must become metallic, because there is no longer sulphur to combine with it. Now this metallic copper, thus prematurely produced upon a furnace bottom saturated with regulus, will take the place of the regulus, and in time convert the whole body of the furnace into the metallic state, causing a heavy and useless lock-up of copper in metal furnace bottoms, while an undesirable by-product is produced. If, however, it is desired to pass the regulus under treatment through the "best select" process, as before described, these inconveniences must be put up with, and are to some extent recouped by the improved quality of the copper produced from the regulus. The accurate arrangement of mixtures and calcination, so as to insure "white metal" as a standard product of the metal furnace, is the object which every good smelter seeks to obtain: and yet I well remember when that very product was unknown in the best German works. In 1845, when I went to Germany, with a view of carrying out the new silver process, I took with me pieces of "white metal," being convinced that that product was the right one to treat. I remember showing it to several of the leading men at Freiberg, who would not believe that it was a pure furnace product, so little was it then known. My old friend Ihle, then the rising young smelting official at Freiberg, who was struggling to get reverberatory furnaces introduced, it is true knew it well, for he had spent some time at the Hafod Works. I took the specimens on to the Mansfeld Copper-Works, where I found them working with 40 per cent instead of 75 per cent regulus in their silver extraction, whereby their costs were nearly doubled. The manager of that works was Herr Ziervogel, the inventor of the silver extraction process, which by his aid I afterward carried out at Hafod. He was one of the ablest metallurgists I ever met, and was the manager of the largest copper-works in Germany; yet at that time (1845) he was completely unacquainted with "white metal," never having concentrated copper regulus beyond 50 to 60 per cent. At first, he was incredulous as to our being able constantly to produce it, and he also doubted whether it would work in his silver process. I, however, insisted upon its being made the basis of our operations; and when he came to Hafod and worked with it, he soon saw I was right: yet when I visited the Gottesbelohnung Works, three years later, I found them still working with 40 per cent regulus, to their great loss and cost. I do not state this from memory, but from full notes made at the time, which are before me as I write. I mention this to show how far in advance of the rest of the world South Welsh copper smelting was when I first knew it nearly forty years ago.

I must now return to our regular copper smelting process. We have advanced to "white metal," pure (or nearly so) sulphide of copper of, say, 75 per cent—Le Play gives it as high as 77·4 per cent, with 0·7 iron, and 21 per cent sulphur. The next process is what we call "roasting," during which the whole of the sulphur is expelled and the copper reduced to an impure metallic condition known as "blistered copper." Le Play's analysis gives it as 98·4 per cent copper; 0·7 iron; nickel, cobalt, manganese, tin, and arsenic, 0·7; sulphur, 0·2. It is very remarkable how completely the sulphur has been driven off. This "roasting" process is a very beautiful and delicate operation; and as I am not aware that any thoroughly good account of it exists, I think it will be interesting and instructive if I read a description of it by our Mr. William Morgan, who has for forty-seven years managed our Hafod Copper-Works with the utmost ability and intelligence:

COPPER ROASTER.

"The material operated on in these furnaces consists of white or pimpled metal from the metal furnace—regule from the selecting process, as well as the metallic bottoms from the same process. In the old method of smelting, for ordinary tough copper, no selecting process was adopted, but the metal just as it came from the metal furnace was used, as is now done, both for tough and best selected copper. The pigs of white metal from the metal furnace are broken into large lumps and introduced into the roasting-furnace by means of a paddle, and piled up as high as possible in the middle of the furnace. The temperature of the furnace is raised very gradually, so as to produce a very slow fusion, the melted metal falling down in drops, all the while subject to the oxidizing action of two streams of atmospheric air, introduced through two holes (plug-holes) at the back of the furnace one in either side of the bridge. After the whole has been melted down, the temperature is considerably raised (the air-holes being closed up for this purpose), and the surface of the melted metal freed by 'skimming' from it any slag floating on the face of the charge. The air-holes are then again opened, as is also the head of the fire-place, and the charge cooled down till quite 'set' or hard. During this operation, called 'setting,' the whole charge becomes a spongy mass, and swells to twice or thrice its original thickness when in a melting state. The theory of the roasting process is just this: When sulphide of copper in a melting state is exposed to the action of a current of atmospheric air, decomposition of the sulphide occurs and sulphurous acid gas and oxide of copper are the result. The thin film of oxide of copper produced on the surface is immediately acted on by the sulphide of copper with which it is in contact, and sulphurous acid and metallic copper are the result, the gas passing off through the chimney, the metallic copper from its greater specific gravity falling through the melting mass to the bottom of the furnace, where it is protected from further oxidation. In the production and reduction of the oxide of copper, dense volumes of sulphurous acid escape, and, as the reduction takes place mainly under the surface of the melted metal, the gas resulting from this reduction forces up the cooling metal, until the whole mass assumes the spongy consistency above referred to. When the whole charge has been thoroughly cooled down, so as to become black and hard, the temperature is again raised, but very slowly and gradually as at the first. The object both of the first slow melting and the subsequent remelting of the cooled and raised mass is the production of surface action. In this way, almost every portion is brought under the oxidizing influence of the atmosphere.

"Generally speaking, long before the whole of the charge has been remelted, the experienced workman finds, from the large production of oxide of copper, that it is necessary to cut off all further access of atmospheric air, to prevent the whole or a large portion of the charge from becoming oxidized. If the oxidizing process has been conducted first to the right point, it will be found, after the whole of the charge has been melted and the surface freed from slag (which is mainly silicate and aluminate of copper), that the copper when tapped into pigs and cooled has a smooth, blistered appearance, which appearance has given a name to the product of 'blistered' copper. This process occupies twenty-four hours, and the charge varies from two and a half to four tons of copper."

This process is essentially South Welsh, although it is now of worldwide use.

The system of concentration from ore-furnace regulus to black copper varies somewhat in continental works; but it may be generally described as consisting of first burning the regulus repeatedly in heaps or in kilns, and then melting it in a blast-furnace, whereby a portion of the copper contents is obtained as black or impure copper of 90 to 95 per cent, with about three per cent iron and one per cent sulphur, while the remainder of the copper flows out as regulus varying from 51 to 61 per cent copper, 16 to 18 per cent iron, and 20 to 24 per cent sulphur. It will be observed that the blast-furnace, owing to its reducing action, produces at one and the same time black copper and regulus never exceeding 61 per cent, while the reverberatory furnace gives one pure product of 75 per cent, which is easily and cheaply reduced into copper of upward of 98 per cent.

The superiority of our process over the other is now universally recognized; and our process has been substituted for the old continental system, I believe, in most works.

The same observation applies to the final process of refining. Here again, I think, I can not do better than read to you an admirable description of our refining process, written by Mr. William Morgan, who has been a practical refiner all his life, rather than attempt to write one myself.

REFINERY.

"The material dealt with in the refinery furnace is the 'blistered' copper produced in the roaster-furnace, and contains from 96 to 98 per cent of copper. The charge occupies twenty-four hours, and weighs from nine to ten tons. It is melted during the night, and remains several hours in the furnace in a melted state. The first operation in the process of refining is the skimming off from the surface of the copper the slag which has been produced in the melting of the charge, in order to facilitate the separation of the last portions of sulphur from the copper. To ascertain when the copper is 'fine,' or when it is perfectly free from sulphur, a portion is taken out in a ladle and allowed to cool. If it still contains sulphur, the copper rises in the center of the ladle, or bubbles out over the surface of the set portion, or shows a number of black spots, generally forming a circle according to the quantity of sulphur still left in the metal. When perfectly free from sulphur, there occurs a depression in the center of the copper in cooling, called the 'set.' When it has arrived at this state, the copper exhibits in the fracture a dull red appearance, and is very brittle and unmalleable. In this state, the copper contains a considerable quantity of protoxide of copper, which has been taken up or absorbed by the melting mass as quickly as formed at the surface. In most cases, it reaches the point of saturation by the time the whole of the sulphur has been driven off, to effect which the surface of the copper is left exposed to the action of the air. The next operation is a reducing or deoxidizing one—to convert the oxide of copper, which the copper holds, into the metallic state. The surface of the charge is covered either with stone coal or charcoal; and in order to bring every portion of the mass under the influence of the reducing covering on the surface of the charge, a pole of hard wood is pressed down into the melting mass, and the ebullition caused by the escape of the gases from the burning pole so stirs the whole mass that gradually every portion of the charge is brought into contact with the carbonaceous covering, when the oxide of copper yields up its oxygen to the carbon on the surface, and the whole mass becomes malleable. The changes which take place during the 'poling' process are ascertained by frequently taking small portions of the copper, and examining the fracture, which, when the process is complete, is smooth and silky. If the process of poling be carried too far, the whole mass suddenly becomes 'overpoled,' in which state the color of the copper becomes much whiter in the fracture, and the copper assumes a fibrous, crystalline structure when broken, and when ladled into a mold, on setting it rises in the center, just as silver does when cooling in a test. Whatever may be the cause of the appearance or condition which is thus called 'overpoled,' whether from the copper taking carbon into its composition, or from its being deprived of the whole of its oxygen, the means of remedying the matter is the exposing of the surface of the copper again to the action of the atmospheric air."

The continental system was to melt the black copper in a shallow "hearth," called a Gaarheerd, like a blacksmith's forge, by means of a blast issuing from a sharply-inclined tuyere, and impinging on ignited charcoal. Slag forms on the surface of the copper, and is from time to time removed. Tests of the condition of the copper are taken; and when these tests indicate that the copper is fine, the blast is stopped, and either the copper is ladled out and cast into molds or taken off in round thin masses ("rosette" copper) as the trade may require.

We have now obtained our copper in a fine and marketable state, containing at least 99½ per cent of pure copper. But what have we got? Is it pure copper? Is it in a marketable state? I am almost disposed to tell you that no ten persons in this room differ more from each other than perhaps the quality of ten succeeding charges of copper made by a copper smelter differ from each other. Mind, I speak critically, not with the enthusiasm of youth, which thinks every face beautiful. I speak of minute differences of quality, generally of no moment, but sometimes of very great moment. I think if I were to ask Mr. Morgan what had been the chief labor of his life, he would reply, "To make good copper." I am sure it has been one of my most constant problems. Now, I have caused a few specimens to be prepared, which will show you upon what minute quantities of what our friend, Jochim Gans, three hundred years ago, not inaptly called "corrupt humors," which we should now call "impurities," the quality of copper turns. Let me first say that copper may be of first-rate quality for all copper uses, and yet very inferior when used for making brass; and when I tell you that nearly one half the copper produced in the world is used for the latter purpose, you will at once appreciate the enormous importance of producing copper of such a quality as to render it available for that manufacture. I well remember when our copper was never tried for brass before it left our works; indeed, I myself introduced the practice even before I took the management of them some six-and-thirty years ago. Many was the cargo of copper we had thrown on our hands by the French brass-makers in those days, and a very unpleasant business it was. We, however, very soon introduced a perfect system of trials for quality which has enabled us to avoid such annoyances. In very early days, I took in hand a series of synthetical trials, which proved of great value. I found chemical analysis slow and most unsatisfactory; traces of this, that, and the other impurity were reported; but who could say to what extent the quality of the copper for one use or another was really affected? It occurred to me that the true way of solving the difficulty would be to take the best copper I could get, and make it bad by various known mixtures of impurities; and I soon found that I was thus enabled to unravel much of the mystery of quality. For the purpose of my lecture to-night, I have caused a few of these synthetical trials to be repeated, and here they are. I do not present them to you as complete or exhaustive, but rather to illustrate this branch of my subject.

Take the case of antimony, it will be seen that the one thousandth part converts first-rate "best selected" copper into the worst conceivable, so bad as to be only fit for casting as brass; short in fracture and a bright yellow. That one four thousandth part makes it unfit for any thing but inferior brass purposes, below the quality known as tough ingot. That one eight thousandth part reduces it from "best select" to tough ingot quality, and that one sixteen thousandth part sensibly deteriorates the quality. You will observe that one one thousandth part of nickel, cobalt, bismuth, arsenic, and phosphorus reduces "best selected" to tough ingot quality.

White nickel and arsenic in combination, and mixed in the proportion of one five hundredth, make copper unfit for brass.

The last trial shows that two substances in combination may often produce a far more hurtful effect than either of them separately. I am indebted to Mr. A. S. Merry for this latter suggestion.

One curious inquiry arises, namely, How is it that any given admixture of another metal with brass causes it to change its character, even if that admixture is infinitely small? I remember well that some thirty-five years ago, just after I had finished my synthetical trials, I had a conversation with the late Mr. George Frederick Muntz, the inventor of yellow metal, who was probably the best brass manufacturer of his day, upon this point, namely, the brittleness and yellow color of bad brass. He told me that he could not explain it, and that, although he had sought an explanation from some of the best chemists of the day, not one of them had been able to give him a satisfactory reply. I was very young at that time, and felt proportionately proud of being able to give him such an explanation as he at once admitted to be satisfactory. It was as follows, and I believe in it is contained the true cause of brittleness and toughness in all metals: During my experiments, I had observed a case—I think it was the admixture of a certain amount of tin with brass, in which the fracture was rough, coarse, and mottled, drab and yellow. Upon close examination, I discovered that this appearance was due to the metal being composed of large crystals. I found that the mottled appearance was due to some of these large crystals being broken through, while others had separated, having their facets bright and unbroken. The former presented a drab appearance, while the latter, reflecting back the light, were bright yellow. I at once saw that the brittleness and yellow color of bad brass were due to the crystallization being extremely small, so that each crystal, being very minute and having an existence separate from its neighbor, parted without fracture, and, possessing unbroken facets, reflected back a yellow light like polished brass. This is further confirmed by the well-known fact that if, instead of allowing bad brass to cool slowly, you quench it in water and thus change its crystallization, it is no longer brittle and yellow when broken. When a metal forms in long crystals in cooling, it is sure to be tough; but when the crystals are fine and sand-like, then it must be brittle. I believe this same law applies to all metals.

Now, having spoken so much of bad copper, I may naturally be asked how to make good and how to avoid making bad copper? I fear my answer can neither be complete nor satisfactory ; but I may at least contribute something toward the solution of the various problems involved in this difficult question.

My first advice is, to do your best to determine beforehand the quality of the ores you have to treat, and never to mix a bad ore with good ores. I speak in the plural because it is surprising how small a quantity leavens the whole lump.

My next advice is, that, when you have once got impurities out of your smelting mixtures, never put them back again. One of the greatest improvements we have ever effected in copper smelting is never to allow roaster or refinery slags to be melted in the metal furnaces, but to treat them by themselves. It is true that by so doing you lose the advantage of their oxidizing action, but that is a small matter compared with the perpetual addition of deleterious substances to your mixture.

Then I would say, avail yourself of the old "best selected" or "regule" process where your material contains impurities which pass into the copper bottom formed in that process. All the foregoing recommendations refer to copper material in course of treatment, not to copper itself when once made. What are we to do with bad copper? My answer is, that that is a question of degree. Copper may be so bad as to be only fit for casting as brass. In that case, make up your mind to sacrifice a pound or two per ton, instead of expending perhaps twice as much in trying to make it better. It is no doubt difficult to make bad metallic copper into good, but by our present improved methods much may nevertheless be done. I think about the year 1851 or 1852, I accidentally hit upon a plan of improving metallic copper, which has stood us in very good stead ever since. I was experimenting on the separation of nickel and cobalt, contained in some ores we were then receiving, by the admixture of arsenic, and I naturally managed to get an excessive quantity of arsenic into the copper so experimented on, which did not improve its quality. Arsenic was retained by the copper through the refining process, and was present in the tough cake copper sent to the mills. This copper was tried by rolling in the usual way, and the trials, which were of course extremely bad, were laid out for my edification and inspection on the iron plates of the mill-floor. To my surprise, in turning them over I saw that the iron plates on which these trials had cooled were as white as if they had been whitewashed. I saw at once that arsenic had been distilled out from the body of the copper, while in the annealing furnace at a red heat, and had continued to pass off even while the copper was cooling on the mill-floor. It occurred to me that what had happened accidentally might be made available systematically, and I caused bad blistered copper to be submitted to a slow, constant, long-continued heat in the roaster-furnace without melting it until it was desired to withdraw the charge. To this process I gave the name of "dry roasting." I see that Dr. Percy, on page 380 of his work of 1861, talks of "dry roasting" practiced in former days, as described to him by an old smelter; but that was evidently a wholly different matter, depending on the exposure of pigs of *regulus* during the greater part of the process of roasting to a less degree of heat than sufficed to melt them, and the roastings were repeated often three times *until* "*blister*" copper was obtained. My plan does not come into operation until *after* "blister" copper is obtained. We always roast our regulus down very slowly; and I do not see how the process above described could have been carried out, since white metal melts at a very low temperature, and parts easily with its sulphur, setting free metallic copper: how the pigs are to be withdrawn from the furnace often three times without melting, I fail to see. I have heard of the frequent calcination of regulus and remelting, practiced in olden days, having the effect of improving quality, and I think the old smelter must have alluded to what was done at some works even in my time, namely, calcining ore-furnace metal only sufficiently to produce "blue" or "red" metal, and then calcining again before producing "white metal." This was called coarse and fine metal melting, but had no relation to the process I have described, which we, I believe, were the first to put in practice. I do not even know that it is used at any other works at this moment. The effect of this "dry roasting" of blistered copper is very marked; we can bring up copper which, if refined without dry roasting, is so brittle that it is reduced almost to powder in passing through the rolls, to a tough quality fit for all ordinary copper uses. This is effected by keeping the pigs of blistered copper at a good red heat in a roaster-furnace for twenty-four hours, then melting and tapping in the usual manner; this process is again and again repeated until the desired degree of quality is attained. I have tried the effect of carbonizing, or, perhaps I should rather say, deoxidizing the copper before tapping, believing that volatile impurities would be more readily sublimed when in a metallic state, but no very sensible difference resulted. The process ceases when the copper is melted.

Another and more recent system of improving the quality of metallic copper is the addition of niter and lime in the refining furnace; to whom the first suggestion is due, I know not; it has been kept, and is to this day, one of those profound secrets which every body knows and avails himself of when it suits him, without imparting it to his neighbor. This process is as follows: 25 lbs. of nitrate of soda and 75 lbs. of lime are intimately mixed and thrown on the charge of copper in the refinery after the slag has been removed: the charge is then poled or "flapped" for half-an-hour, and then the slag is skimmed off. If the first operation does not sufficiently improve the copper, it is repeated again and again. We have found that the quality of copper is decidedly improved by this system, both for brass and copper uses; but I have reason to fear that it is attended with some loss of copper, and it is also expensive if often repeated.

Before taking leave of copper-producing industries, I ought briefly to mention two most important systems by which copper is extracted from pyrites rich in sulphur and poor in copper by the wet way; the one I have already alluded to, namely, the system adopted in Spain at the great works of the Rio Tinto and Tharsis companies and at those of Messrs. Mason & Barry; the pyrites is placed in large heaps in the open air; these are set on fire by a layer of wood placed beneath, and continue to burn for many months; the copper contained is partially converted into sulphate, the burnt ore is then washed with water in vats, whereby the sulphate of copper, being soluble, is extracted ; the liquor is then run over iron, whereby the copper is precipitated and collected in the metallic state. The residua of this lixiviation are then deposited in immense heaps with a certain proportion of raw pyrites, water is laid on, and the remaining portion of copper is said to be completely washed out in some six years ; the liquors issuing from the base of the heaps are, of course, collected, and the copper they contain is precipitated in the manner described above.

The other process is that of Mr. Henderson for the treatment of the burnt pyrites obtained from the kilns of sulphuric acid makers. I have never seen this process, and it would therefore be improper that I should do more than mention it as a process which has proved eminently successful for the treatment of that material, extracting the copper, I believe, very completely, and leaving a residue composed of almost pure oxide of iron, valuable in iron smelting. I am informed that the burnt residua of the kilns are calcined with salt so as to convert the copper into a chloride, which is partly volatilized and condensed and partly obtained by lixiviation—first with water and subsequently with dilute hydrochloric acid.

THE BALTIMORE COPPER WORKS.*

In this country, copper ore smelting, as disconnected from concentration at the mines, and distinct from the melting and casting of native copper, was carried on for some years in five different places—at Boston, New Haven, Taunton, within New York Harbor, and Baltimore.

As elsewhere, the cost of carriage of that part of the ore, or concentrated product which is not copper, discriminates against this particular industry, which is bound to decrease in extent as facilities in the mining regions themselves increase.

Geographically as well situated as England for drawing supplies of ores from abroad, the economic conditions, however, when at their best, were unfavorable compared with those at any time obtaining there. The home mines were not very important; hence the natural basis for the business of such works remained local, and since spontaneous arrivals of ores from South America could not always be counted upon, heavy commercial risks of importation had to be taken. The industry enjoyed some protection through customs tariffs, but, of course, only against foreign competition.

The huge exploitations of our Lake Superior mines of native copper, requiring no smelting, became a new element; the sometime instability of the currency and of prices made the business not very safe commercially.

All these causes operated to bring about a total cessation of copper ore smelting as a commercial industry in this country some ten years ago.

Only one of the six works at one time running is now in existence, and flourishing—the one at *Baltimore*. And it is a stubborn fact (stubborn as any thing Welsh can be—which surely is emphatic enough), that the main reason why that establishment is in existence, and the others not, lies in the steadfast faith, incarnate there, in Mr. Vivian's doctrine, "South Wales against the world."

Adhering to the Welsh copper smelting process pure and unchanged, the Baltimore works had turned out *good* copper for brass. The other works, having mixed in the German practice of blast-furnaces, never had.

That one main result, good copper, could be relied on at Baltimore, and upon the faith of it there was again built up a business which at this time has assumed large proportions and rests upon a solid basis.

The Baltimore Copper Works were started in 1844, by a stock company, called the Baltimore & Cuba Smelting and Mining Company, in connection with a mining scheme never undertaken. Prominent merchants of Baltimore, however, became identified with it, and smelting was seriously undertaken.

Mr. Hazlitt McKim, now a banker in New York, and the late Dr. David Keener, were the managers. A whole colony of smelters was imported from Wales, and the furnaces built on Locust Point, where now are located the grain elevators and steamship wharves, but then a waste tongue of land; historical ground, however, as on it waves the star-spangled banner of Fort McHenry.

The company subsequently divided, and Dr. Keener built in 1846 new works on the opposite shore, at Canton, of which a sketch as it looks to-day, is given in this work.

The business of Dr. Keener's company was very successful and profitable. It was wound up in 1861, the works being sold to the other company, who then for a number of years—during the civil war—ran both works, the President until 1867 being the late Clinton Levering. That at Locust Point was in 1868 sold to the Baltimore & Ohio Railroad Company for terminal purposes; the Canton works finally suspended through losses in the business, mainly occasioned by bad commercial operations, currency fluctuations, and the radical change in the tariff of 1869. Mr. John W Garrett and the late Johns Hopkins took a lively interest in the affairs of the company, and were so well satisfied of success under reasonable management that they joined the present owners in reviving the Baltimore Copper Works at Canton in 1872, which were thenceforward and are now conducted under the firm of Pope, Cole & Co., by whom the business is managed in a strict mercantile way and with marked success.

The Welsh smelters, transplanted from a field where the ugly, rebellious ores of Cornwall, etc., made success in good copper smelting difficult, as Mr. Vivian amply testifies, encountered a new condition of things at Baltimore. Instead of finding impure ores, instead of having to practice the selecting process and making several grades of copper, they found only pure ores, and could only make one grade of copper, and that better than any they had been able to make from the promiscuous ores sent to Wales. They found the best of long-flame coal only as fuel, instead of the laborious mixture of coal imposed on them in Wales. They were allowed to retain their customs and liberties, and thus really transplanted their particular industry in its integrity to Baltimore; were content, and taugh the handicraft to their sons. That they made uniformly good copper, was due to their skill and discipline no more than to the fact that tin, nickel, antimony, arsenic did not exist in the ores which came into the works for years, these metals never being found in the copper mines on this side of the Rocky Mountains. These pure pyritous ores were a very different furnace material, had a very different effect in mixtures, than those at home. Hence, the work of the men resulted better in all respects than in Wales. The brand of "Baltimore Copper" became as famous as the painstaking manager, Dr. Keener, became popular in the manufacturing districts of New England. His chief smelter, Mr. Davis, is still superintendent at the works.

There were smelted at Baltimore the ores and mattes of Tennessee, of Virginia, Maryland, Vermont, and of Lake Ontario, all pure sulphurets, mixed with the rich ores of Chili, especially such from the famous mine of Sr. Urmeneta, the late President of Chili, with whom an excellent contract had been made. After the civil war, California sent many cargoes of sulphurets, and Arizona of rich oxides, to the wharves at Canton Copper Works. Lake Superior sent her native mineral there to be melted, before the refineries at Cleveland and Detroit were built; and indeed it was a detachment of Welsh smelters from Baltimore who built the furnaces and taught the Lake Superior people how to melt and refine their copper. And for years, both here and in Europe, the brand of "Baltimore Copper" was considered quite equal to Lake Superior copper, and the quantity produced in Baltimore was greater for a long time than that of the Lake mines. Baltimore has produced as much as 10,000,000 pounds of refined copper per year.

The plan of the works at Canton was designed with a view to future growth. Originally only three acres, the land has been made to grow by the filling in of slags and *débris* to some five acres; they are admirably situated upon deep water, so that the largest sized vessels can discharge at the wharves; the division of the ground and buildings to serve for the various departments of work of the several industries which have been engrafted upon the original copper smelting works does justice to the policy of the founder; the arrangement is harmonious, although the additions were made by piecemeal.

There were formerly in the works eighteen reverberatory furnaces for smelting and metal working, two refineries, three calciners, worked by two great and four or five lesser stacks, a fire-brick house, crusher, one assay office, with lesser shops, all under lofty roofs, extending over coal sheds in the rear, with plenty of yard room. Five ore-houses were built of slag stones, from which also was built a handsome wall around three sides of the property.

Subsequently, upon some extremely crude notion and without regard to its economical relation to copper smelting under changed conditions, a handsome sulphuric acid chamber system had been erected near the wharves.

When the works came into the hands of Messrs Pope, Cole & Co., the commercial aspect as well as the nature of the supply of furnace stuff was almost totally different from what it was in the earlier history of the business. Poor ores no longer came; instead of them, regulus, rich ores black copper, argentiferous and auriferous mattes and speiss from our Western territories. It became now necessary to add new processes to the old system of smelting, and to practice "selection." This is done radically. Into the department where the Baltimore Copper—branded "B. C. W."—is made, nothing is admitted except well-known pure and soft material. The rest goes to the departments of silver extraction, blue vitriol making, and residue treatment. These departments are fenced off: each has its own tools, furnaces, staff, and workmen. The silver extraction is worked by ingenious processes differing from those elsewhere practiced quite materially. The blue vitriol establishment is the largest and most complete in the country, turning out an extremely popular quality for all uses, and an unsurpassed extra kind for the fine color manufacture. There are now in the works three refineries—and room for three more—many metal and ore furnaces, two blast-furnaces, four steam-engines eight boilers, sixty tanks, and machinery to work it all.

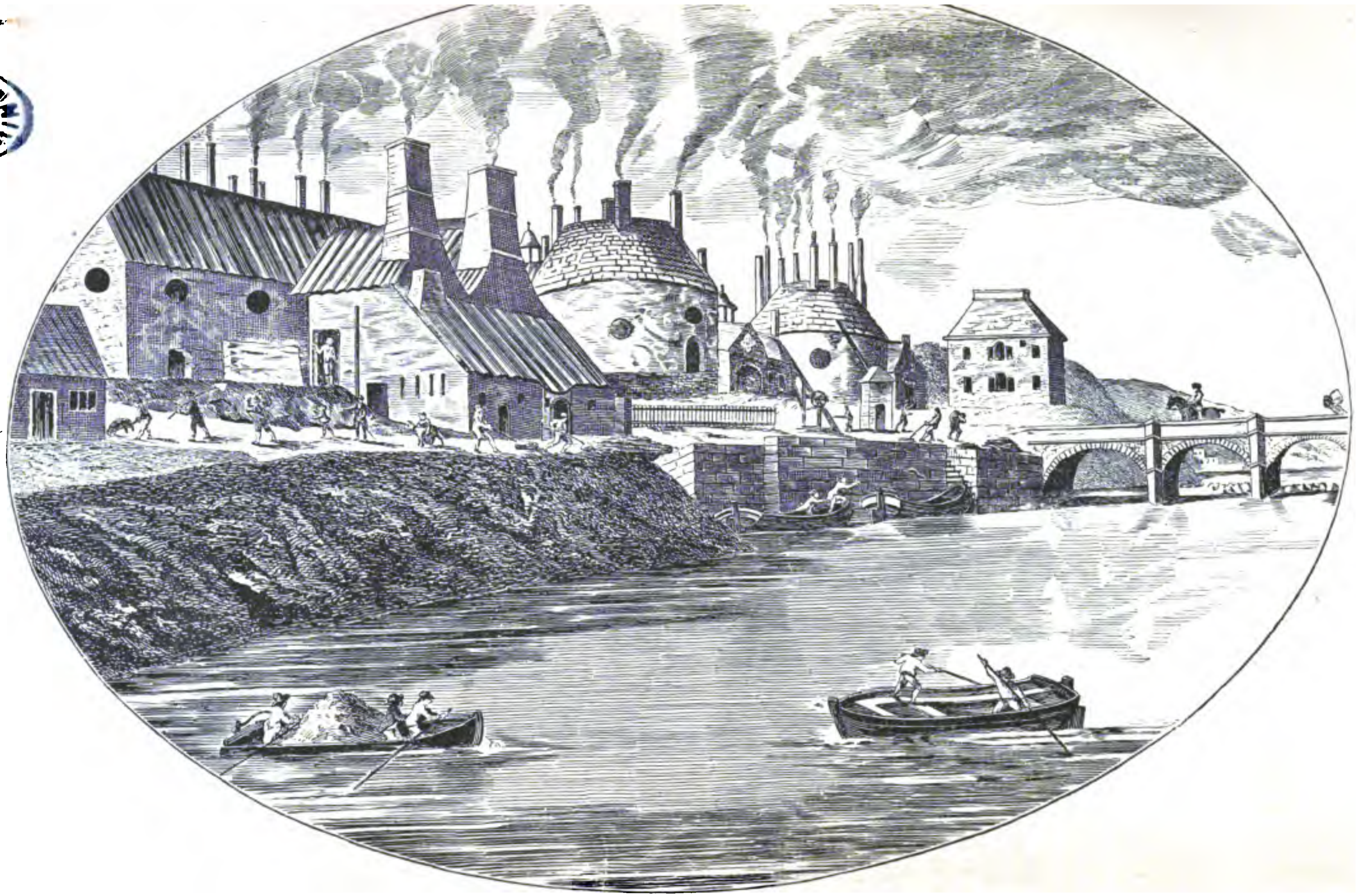
The scientific department is superintended by G. W. Lehmann, Ph.D.

and assistants, who use three separate assay offices and make independent assays and analyses. Weighing, sampling, keeping of accounts, are all systematized in the completest manner; errors are unknown in all these details. All repairs are made in the shops on the ground, and the smallest piece of old iron is husbanded.

One of the firm spends all his time at the works, and through the telephone, etc., can manage every thing inside and outside the works with rapidity.

The capacity of these works is very great; for the treatment of such rich and pure copper material as now comes forward from the Southwest and Northwest, it is practically unlimited. The proprietors are progressive men: besides understanding the metallurgy of copper, the staff at these works has produced on a working scale, by way of a demonstration, 150 tons of chemically pure zinc out of impure spelter and dross; also equally pure carbon harder than emery; and at present, experiments in electro-metallurgy are making, which may add to the facilities of the establishment largely. The great influx of argentiferous copper material from the Western mines necessitates a further extension of the works.

UNIV. OF MICH.



The Engineering & Mining Journal

THE OLD FOREST WORKS AT SWANSEA.

Photographed from a view taken in 1794, showing the circular arrangement of furnaces. From the original in the possession of Lieut.-Colonel [illegible]

THE FOREST COPPER WORKS.

[This and the following paper are taken from an unpublished work, entitled, *The Smelting of Copper in the Swansea District, from the Time of Elizabeth to the Present Day*. By Major GRANT FRANCIS, F.S.A., etc. Swansea. 1867. The concluding paper explains itself.]

These works are situate some half-mile north of Llangavelach Works on the Swansea River, and were built in the year 1727.

The greater facility of getting in coal at that point was possibly the reason for the removal, and it has been suggested that the question of "smoke" had begun to prove troublesome.

If it is difficult to fix with any thing like precision the date of the opening of the various works, to ascertain the period of their closing is still more so—is, indeed, rather to be gathered incidentally than positively; thus, in a previous page I ventured to indicate that the Llangavelach Works were not in operation in 1761, and the balance-sheet of 1768, which will presently be laid before the reader, goes to prove the fact that the words "Old Copper Works" on the estate-plan may simply mean that they had been there a long time. The view of the Forest Works, taken in 1794, which I have had revived by photography, gives an excellent idea of the arrangement of the furnaces, surrounded and connected by a circular wall, and covered over by one roof, a plan doubtless adopted for the convenience of working as well as for the privacy which was thereby insured, and which in the early times of the trade we have seen was forced on the workmen by the administration of oaths specially authorized by the crown charters! In one of the many obliging and interesting letters for which I am indebted to my friend, Mr. William Edmond, of Clase, he says: "In 1747, an assay office was built at Forest, and is still in existence, and an underground canal, which brought the coal direct into the works. The accounts of 1743 show that they had rolling-mills and hammer-mills ('Batterry Works') on the site now occupied by the Beaufort Iron-Plate Company, built convenient to its smelting-works at the Forest; and if the 'Llangavelach Works' mean those at Landore, it must have been very inconvenient to haul all their copper from Landore to Forest. The Forest or Llangavelach Works are not those at present existing at Forest; for in 1834 I was present at the removal of the last of the old buildings. They were formed of four large *circular* buildings; the furnaces were arranged so that, the fire-places being on the outside of the circular walls, the furnaces were within them, concealing all that was going on. In the center of these four circular houses stood the 'refinery,' which is still there, and is octagonal in shape. The public road anciently went *under* an arch at the refinery, and crossed the river at the Hen Bont, an old bridge a little above Mr. Hallam's present tin-plate works."

When, precisely, the first firm of Lockwoods & Morris ceased to be connected with those works, I have not yet ascertained ; but the Rev. J. Evans, in his *Tours in South Wales*, in 1803, mentions "Mr. Morris of Clasemont" as one of the then existing eight copper smelting firms in the Swansea District. In times more within our immediate ken, it is not difficult to remember "Forest" in the hands of Mr. Troughton, a gentleman of some chemical and mechanical skill, who, formerly in the navy, turned his abilities, under a patent, to the more ancient and ill-smelted slags, in the crushing, mixing, and remelting of which he found ample occupation, if not profit. The next firm who seated themselves there were Messrs. Usborne, Benson & Co., which shortly mutated into Benson, Logan* & Co., from whom they passed, under a new lease for twenty-one years, in March, 1845, to the English Copper Company ; but the latter having more works on hand than proved convenient or profitable, it surrendered the lease up to the Duke of Beaufort, as ground landlord, in 18—, and they have ever since remained idle.

To those interested in copper smelting and its details, it will scarcely be possible to supply more interesting matter for comparison than the balance-sheets of the two works, not merely on account of the particulars which they contain, but because they both notice "the Swansea Copper Works," and that in 1768 the Forest works and mills accounts were still unclosed ; and that therefore probably they were not at that time completed. As in the previous sheet, so in this, the names of the partners, with their respective profits, are distinctly set forth.

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*Now [the late] Sir W. E. Logan, F.R.S., the eminent geologist, and Director of the Government Geological Surveys in Canada.

* * *

THE HAFOD COPPER WORKS.

The year 1810 saw the commencement of these now celebrated works at Swansea, on the lands of that name, belonging to the Duke of Beaufort and the Earl of Jersey, granted by lease in that year to Messrs. Richard Hussey and John Henry Vivian. Their father, John Vivian, Esq. (whose family in connection with metallurgic manufactures has now obtained a world-wide reputation), I have already stated, first came over to Wales from Truro in Cornwall, on behalf of himself and other mine-owners.

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The prosperous state of the trade, and the very great increase of furnaces along the banks of the river, created such volumes of sulphurous acid gas (the so-called copper smoke) that at length the neighboring landowners began to complain of the mischief to their stock and crops, and legal proceedings being threatened, it was at these works that the first series of experiments (with the stimulus of a thousand pounds reward for the abatement of the nuisance) were conducted by Professors Faraday and Phillips, under the immediate supervision of the then managing partner, Mr. John Henry Vivian. No effort was wanting, no expense spared, but alas! success was not *then* to crown their efforts. As in the course of events the chief direction of these great works fell to the share of Mr. H. Hussey Vivian, M.P., so the copper smoke now is by that gentleman likely not merely to be abated, but converted into a means of profitable use for the manufacture of superphosphate manures—a kind of chemical retribution little dreamt of a few years ago.

The late Mr. J. H. Vivian informs us that the first trials to this end, worthy of note, were made at Hafod in May, 1820, and that the eminent Davy took a lively and personal interest in the subject in the year 1822; that further experiments were continued at Hafod. and improvements to the same end were publicly notified, so late as 1832 and 1833.

Of the original partners and brothers, the elder entered the army, and greatly distinguished himself in the Peninsular war, and was created a baronet for his eminent services, and eventually, on retiring from his command in Ireland, was created a peer, by the title of Lord Vivian. The junior, Mr. John Henry Vivian, devoted himself to commercial pursuits, and turning his natural abilities and early scientific training to account, became sole managing partner and eventual owner of the Hafod Works, and the admitted head of the copper trade in this country. Mr. Vivian was made an F.R.S. for his paper on copper smelting, which was printed in the Royal Society's Transactions. He was also one of the first members of the Geological Society, and in 1832 was elected to represent Swansea, Neath, Aberavan, etc., in the first reformed Parliament, the which he continued to do in six successive parliaments, until his death, in 1855; and, having greatly endeared himself to his constituents and friends, a bronze statue to his memory was erected in the Guidhall Square, Swansea.

To Hafod, foreigners now resort who desire to see its great staple in course of manufacture; to Hafod, the cadet classes of Woolwich annually repair for instruction in metallurgy; and great as was its progress under the late Mr. Vivian, it still retains its eminence under the management of Mr. Hussey Vivian, whose father's mantle has fallen on shoulders fully equal to the position.

Hafod is now the center of a busy population, surrounded by several of the works which I have attempted to describe, denuded of every vestige of verdure.

THE SMELTING OF COPPER IN THE SWANSEA DISTRICT.

TO THE EDITOR OF THE CAMBRIAN:

SIR: My communications in your columns on this subject last year satisfactorily proved the very commencement of this important manufacture in this district to have taken place at Neath in July, 1584;[*] but I was at the same time obliged to confess my regret that I had been unable to discover the precise date when the first copper-works on the *Tawe* were erected,[†] although we know they were at work in 1745.

I am now, however, in a position to fix the very year in which the trade began near Swansea, as the following extract from a document still in the muniment room of our corporation will show.

For the purpose of some proceedings at law, on the part of the burgesses, "a case" was prepared for counsel, and "the opinion" given thereon is signed N. Fazakerly, April 19th, 1734. Among other matters, the town clerk of that day set forth that "*in the year* 1717 *works were first erected upon the river of Swansea for smelting copper and lead ores*, which works are scituated above the town, and about two miles beyond the extent [boundary] of this corporation. In the year 1720, another work was erected upon Swansea River for smelting of copper ores,[‡] and scituated within the limits of the corporation," etc.

So that, historically, we know that the smelting of copper at its present several centers in this district was as follows:

At Neath, by the Mines Royal,	in the	year	1584
At Swansea, by Dr. Lane	"	"	1717
At Aberavan, by Newton & Cartwright	"	"	1727
At Penclawdd, by John Vivian	"	"	1800
At Llanelly, by Daniel, Nevill, and others	"	"	1805
At Loughor, by Morris & Rees	"	"	1809
At Pembrey, by Mason & Elkington	"	"	1846

I am glad to have thus filled up the only important hiatus in my work, and shall have pleasure in supplying any one who has a copy of the book with this additional information in print, to go in at page 71, under the head of "Llangavelach Works." I remain, sir, yours faithfully,

GEORGE GRANT FRANCIS, F.S.A., Lieut.-Col.

CAE BAILEY, Sept. 22, 1868.

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[*] Vide my work on Copper Smelting, 8vo, 1867, p. 8.
[†] See ditto, volume, p. 71, Llangavelach Works.
[‡] See ditto, p. 69, Swansea Works.

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